INSPECTION ORGANIZATION AND METHODS

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INSPECTION ORGANIZATION AND METHODS

DEDICATED TO THE MEMORY
OF MY FATHER

FRANK EDGAR THOMPSON

WHO ENCOURAGED MY QUESTIONS
TO DEVELOP A SEEKING MIND

PREFACE

Books usually represent the effect of some cause, and this text is no different in that regard. During the Second World War the author "inherited" the position of director of inspection at a large precision machine shop, as the by-product of a management counseling assignment. The operational problems were many and vexing, and the solution for each was usually obtained through logical investigation and deduction, fortified by a certain amount of experimentation. The author searched in vain for printed material, in both books and magazine articles, that would cover a majority of the basic organization, operation, and human relations problems that were encountered.

The experience gained in that instance—modified by subsequent work as a management engineer engaged in developing organization, procedures, and methods for other inspection activities—augmented by a personal postwar survey of inspection organization and methods at over twenty large industrial concerns, forms the basis for material contained herein. Logical, roven, functional organization patterns are established for the nspection department. Practicable methods of controlling and recording the flow of work to ensure integrity of the product and maintain harmonious relations with other factory departments are presented. The greater emphasis is placed upon organization, procedures, and methods. The tools of inspection and their usage are simply the mechanical implementation of basic management policy, and a general understanding of the correct usage of inspection equipment is assumed.

Certain procedures and methods outlined herein may be too extensive for some conditions, and suitable adjustments should be made in their application. In each case, however, the basic objectives are clearly defined. Adjustments for individual conditions should not compromise realization of these objectives.

The assistance of the many organizations and individuals who have furnished data and illustrations for this book is deeply appreciated by the author. Appropriate acknowledgements of their assistance appear in the text.

Special acknowledgement is due Beech Aircraft Corporation, Chance-Vought Aircraft Division of United Aircraft Corporation, Fairchild Engine and Airplane Corporation, McDonnell Aircraft Corporation, and Northrop Aircraft, Inc., for supplying the author with reference copies of their inspection department manuals. These publications were invaluable in establishing the upper limits of procedures adequate for control of quality for products of extreme precision and complexity; and in determining the general outlines of certain functional responsibilities detailed in Chapters 4, 11, 12, 14, and 15.

The author is especially appreciative of Laura E. Thompson's invaluable assistance in typing and indexing the manuscript; and of the many suggestions for improvement made by W. W. Lampkin, Assistant to General Manager, Hughes Aircraft Company, Culver City, California, while reviewing the final manuscript.

JAMES E. THOMPSON

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January, 1950

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CHAPTER 1

OBJECTIVE AND PLAN

Efficient management depends upon the application of six fundamentals: (1) complete understanding of the goal; (2) a detail plan for reaching the goal; (3) a simple, practicable organization; (4) competent personnel; (5) control of the work; and (6) adequate follow-up. When these fundamentals are correctly understood and applied, management will have control of *objective, operation, organization, man power, methods,* and *schedules.*

These fundamentals are universally applicable to every segment of management—whether it be Inspection or Accounting. Once the objective is crystallized, it becomes possible to formulate a logical plan for operation. This should not be confused with establishment of operational standards and procedure. Instead, it concerns establishing a plan for operation of a department as a unit of the company, and in its relation to other units.

Inspection's basic objective is maintenance of product integrity to facilitate profitable operation and customer satisfaction. Its duties encompass detection of defective workmanship, determination of causes of chronic defects, and guidance of manufacturing personnel in eliminating causes of defective workmanship.

Thus it becomes apparent that Inspection is a *service group,* acting as the guardian of product integrity and aiding other departments in eliminating manufacturing defects. Inspection should never overlook its service capacity and must maintain friendly cooperation with all departments of the company. This may be difficult at times, particularly when manufacturing departments are making an all-out effort to meet production schedules.

Conflicts regarding rejected items can usually be avoided through adherence to Inspection's prime objective of making certain that all workmanship is in accordance with relevant engineering drawings and specifications. Inspection's personal viewpoint is of little consequence; and all affairs involving rejection, rework, salvage, and scrap should be handled in strict conformance with pertinent engineering data. Only in this manner can Inspection avoid being accused of rejecting work simply for the purpose of asserting its authority.

TYPES OF INSPECTION

Physical inspection is the implementation of quality control and, together with recording and systematic analysis of manufacturing defects, provides means of maintaining product integrity at the desired level. The terms *quality control* and *inspection* are often used interchangeably, and it is pertinent at this juncture to define each clearly, and to establish their proper positions within the framework of a manufacturing enterprise:

Bethel, Atwater, Smith, and Stackman[1] define these terms as follows:

> . . . quality control . . . is a technique of management for achieving quality, whereas inspection is . . . a part of that technique. Any quality-control program relies on inspection together with the reporting, collecting, sorting and analyzing of inspection results to indicate wherein a lack of quality control exists.

Thus it becomes apparent that quality control is not another form or method in inspection, but rather that inspection is the means of maintaining a level of product quality compatible with its end use and permissible manufacturing cost. It is important that this basic concept be clearly understood, as there appears to be some confusion regarding the relationship between quality control and inspection.

All manufacturing enterprises make some attempt to control the quality of their product through establishment of minimum acceptability requirements for parts and assemblies. The inspec-

[1] "Industrial Organization and Management," p. 376, McGraw-Hill Book Company, Inc., New York, 1945.

tion department has the task of making certain that these requirements are met and that product integrity is maintained at the required level.

Throughout this discussion of organization and methods for maintaining product integrity, this duty is considered the sole responsibility of an inspection department, headed by a chief inspector. It is founded upon a basic plan of two prime activities of "physical inspection" and "inspection analysis" reporting to the department head; and it is applicable to any enterprise engaged in the manufacture, operation, or maintenance of products produced as a result of fabrication and assembly operations.

The basic function established through application of this concept could easily become a *quality-control department*, by simply substituting the title of quality-control manager for that of chief inspector. Identical functions would be involved in both cases. This parallelism of inspection and quality-control can be readily demonstrated by comparing basic inspection functions with the quality-control duties outlined by Bruno A. Moski, Jr., plant manager of The American Paper Goods Company, in the following summary.[2]

Quality-control Fundamentals

1. *Purpose of Quality Control*

   Quality control is a tool of management used to maintain and improve the quality of products to meet competitive standards and reduce the cost of waste.

2. *Fields of Application*

   a. In theory, quality control is essential in all industrial enterprises.

   b. In practice, its value increases with the ratio of the cost of waste to the total cost of the product.

3. *Principles of Quality Control*

   a. Establish definite standards of quality, and define clearly the responsibility for the maintenance and control of quality.

   b. Evaluate the cost of deviations from quality standards, in order to budget the cost of an effective quality-control program.

   c. Determine when 100 per cent inspection is necessary, and when inspection by sampling is sufficient.

[2] *Factory Management and Maintenance*, November, 1948, pp. 136 and 138; with a few parenthetic additions by the author of this book.

d. Establish physical inspection methods on the basis of motion-study principles.

e. With increased proficiency in quality control, utilize statistical methods of quality control.

f. At all times, the control of quality should be subject to review for maximum effectiveness at minimum cost.

4. *Quality Standards*

a. Quality standards are generally established on the basis of competition, ultimate use of the product, or selling price of the product.

b. In all cases, the specific quality standards should be defined by the product engineering department, or the comparable department which is responsible for design of the product.

5. *Maintenance of Quality*

a. After quality standards have been established, it is the responsibility of the manufacturing supervisory staff to maintain them.

b. From group leader to plant manager, each level of supervision should be familiar with the standards, be in agreement with them, and should exercise due authority to insure that all products are manufactured according to standards.

c. It is the responsibility of the inspection department to check the effectiveness of manufacturing supervision in adhering to the standards.

d. It is not the purpose of the inspection department to relieve manufacturing supervision of the basic responsibility for quality.

e. In a sound organization . . . quality control . . . reports to the chief engineer (or some other member of top management who is not directly responsible for production) to avoid possible weakening of quality standards by manufacturing supervision.

6. *Evaluation of Quality*

a. In quality control, economics should guide the planning of the program.

b. Before specific courses of action are determined, it is desirable that the actual cost of deviations from quality standards be carefully evaluated.

c. Deviations from quality standards generally fall within the following groups: (1) *raw-material waste,* including the cost of raw material in excess of minimum waste resulting from economical manufacture of the product; (2) *scrap,* including the

cost of raw material, labor, and overhead resulting from products rejected at any time after the first operation; (3) *rework*, including the cost of excess labor required to salvage rejected products; (4) *credits allowed customers* because of product defects determined after the product has been sold.

d. When deviations from quality standards are evaluated, and projected on an annual basis, it is possible to establish a reasonable cost-reduction objective, justifying an annual operating budget for the quality-control function.

7. *One Hundred Per Cent Inspection*

a. The most costly type of inspection is that in which 100 per cent of the product is inspected after every operation.

b. Because of the expense involved, 100 per cent inspection should be avoided wherever possible.

c. Such inspection may be justified in complex electrical and mechanical products at the completion of final assembly, and in comparable examples, or at critical stages in the manufacture of intricate-detail parts or assemblies.

d. In general, 100 per cent inspection should be approved only where excessive cost (or injury to personnel) results from failure of the product.

8. *Inspection by Sampling*

a. Inspection by sampling represents quality control at the maximum of effectiveness—by controlling quality with minimum cost.

b. First analyze all operations, to determine the minimum points where inspection is required.

c. It is then necessary to determine the degree of accuracy required in the final product.

d. In other words, for each point where inspection is required, decide the acceptable percentage of satisfactory parts in each lot to progress to the next operation.

e. On the basis of the acceptable percentage of satisfactory parts in each lot, select a sample that is sufficiently large to include a similar percentage of acceptable parts, according to the law of probability.

f. The sample selected should be truly representative of the entire lot.

g. Inspect the sample 100 per cent, and determine the percentage of satisfactory parts.

h. When the percentage of satisfactory parts in the sample is equal

to or greater than the permissible percentage, the entire lot of parts may be passed.

i. When the percentage of satisfactory parts in the sample is less than the permissible percentage, (1) the entire lot may be scrapped, which would represent maximum loss; (2) the entire lot may be inspected 100 per cent, scrapping only the defective parts, representing medium loss; (3) the entire lot may be inspected 100 per cent, with rework performed on the defective parts to meet quality standards, representing minimum loss.

j. Whether 100 per cent inspection or inspection by sampling is selected, all physical inspection methods should be established on the basis of motion-study principles, for minimum inspection cost.

9. *Statistics of Quality Control*

a. The technique of inspection by sampling may be further refined by the application of statistical methods.

b. Statistics are used to determine (1) the size of a sample which is necessary to insure the probability of its being representative of the lot; (2) the probable percentage of satisfactory parts in a lot, on the basis of an analysis of the sample; (3) the extent and trend of a process getting out of control with respect to quality standards.

10. *Control of Inspection*

a. Assurance of maximum quality at minimum cost is obtained through the systematic audit of inspection tools, procedures, and results.

b. At regular intervals check physical gages against master gages and standards.

c. Periodically review actual inspection techniques, including the statistical methods, in order to improve the economic control of quality.

d. Apply the principles of inspection by sampling to the work of inspectors, to minimize errors caused by the human factor.

PRODUCTION INSPECTION

Production inspection involves maintenance of the required product quality through the cycle of tooling, fabrication, assembly, and testing involved in manufacturing. The degree of product quality to be maintained should be based upon customer requirements. High quality normally results in higher manufac-

turing costs and the necessity of a higher cost to the customer.

In the case of products built under contract to a specified customer, certain quality requirements are normally part of the contractual stipulations, and the unit cost is established accord-

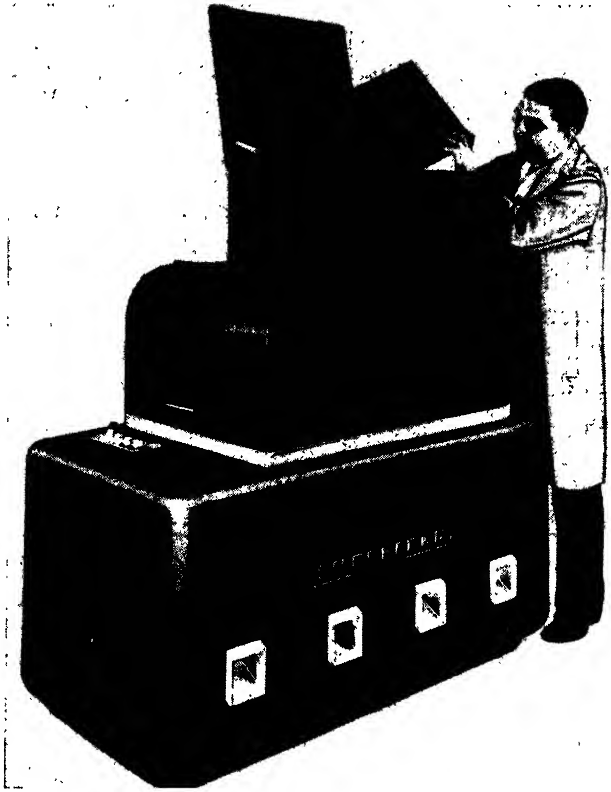


FIG. 1:1. Automatic gaging machine. (*Courtesy of the Sheffield Corporation.*)

ingly. Articles produced as speculative manufacturing (*i.e.*, for sale to the public through normal trade channels) normally maintain quality standards compatible with the economics of manufacturing. The quality standards selected must be high enough to avoid jeopardizing the manufacturer's integrity, avoid customer dissatisfaction, and still maintain manufacturing costs within competitive limits.

In all cases, irrespective of the degree of quality requirements

maintained, production inspection involves establishment of safeguards to prevent inferior materials and defective components being used in company products. This involves all basic manufacturing operations, including tooling, receiving, fabrication, assembly, and shipping.

On this basis the objective of a production-inspection activity requires that it (1) check all production tools and gages, and release these for use by manufacturing departments only after definitely establishing their ability to produce items[3] of the required quality; (2) provide adequate inspection and establish positive safeguards over manufacturing operations to maintain product integrity; (3) inspect items (parts and assemblies) produced by the company and its outside production sources at the point of manufacture; (4) analyze the causes of all rejections and make recommendations for corrective action; and (5) cooperate with both Sales and the customer to make certain that all market and customer requirements are properly interpreted and satisfied.

EXPERIMENTAL INSPECTION

Experimental inspection involves maintenance of the required quality standards during development and testing of new designs. Inspectors in the experimental department work closely with Engineering, and often must work without the aid of drawings or other detail reference material. This requires excellent judgment in all actions, and only the most highly experienced personnel should be assigned experimental-inspection duties.

It will frequently be discovered during experimental inspection that certain fabrication and assembly operations are extremely difficult to perform. These indicate potential difficulties during subsequent production of the end item,[4] and can serve as a basis for developing detail inspection requirements for the end item's production. Inspection also should call these difficult operations to the attention of Engineering and request design changes, to eliminate their causes.

[3] *Item* is used herein as a general term identifying any material, part, or assembly involved in manufacturing the end item.

[4] *End item* is the finished product, ready for delivery to the customer.

The basic objective outlined for production inspection applies equally well to experimental inspection. The inspection operations vary only in that fewer items are examined, finer detail and greater skill are involved, and more ingenuity must be exercised in salvaging items that have been improperly manufactured.

MAINTENANCE INSPECTION

The inspection objectives described in the preceding paragraphs are predicated upon an inspection department engaged in maintaining quality standards for manufacturing operations. Another type of inspection department is primarily occupied with the maintenance of factory and fleet equipment. This is often referred to as "maintenance inspection" and is most frequently encountered in processing plants and transportation enterprises.

Inspection's duties in this case primarily involve (1) periodic inspection of machinery and equipment to insure safe, efficient operation; (2) making certain that equipment requiring overhaul at specified periods receive proper attention; (3) inspection of items removed during overhaul operations, to determine feasibility of repair; (4) inspection of all maintenance items received from vendors; and (5) control of the quality of all new and used items produced or repaired in the maintenance shops.

It is apparent that Inspection's objective in this case is not greatly different from that required in a manufacturing plant. Greater emphasis is placed upon salvage determination, as a majority of inspection work involves examination of used items removed during maintenance work to determine the feasibility of their repair. In addition, Inspection has a new responsibility of making certain that all equipment requiring periodic overhaul receives attention at the required times. This function assumes major importance in the case of an activity such as an air line, where government regulations require that a variety of equipment receive stipulated overhaul operations at designated periods. In such cases Inspection has a clearly defined responsibility to maintain accurate records of the location and usage of a

variety of equipment, and to make certain that each is withdrawn from service for overhaul at the proper time.

INSPECTION PLAN

The first step in establishing an inspection plan is determining the degree of inspection required. This will be governed by the nature of the product or operation, and by comparison of the costs of maintaining higher quality standards with possible loss through delivery of defective products or possible shutdowns resulting from equipment failures. Consideration of this subject is confined to production inspection, it being assumed that identical basic considerations apply to experimental and maintenance inspection.

The degree of inspection deemed necessary can range from 100 per cent inspection of each operation on every item to simple functional testing prior to delivery. Both conditions represent extremes and are rarely justifiable. The former can be justified only either when unit manufacturing costs on each part are extremely high, and unusable parts should be discovered as soon as possible to avoid costly, useless work; or when failure of the end item will endanger life or property. The latter procedure can be justified only in cases of a simple end item, wherein all likely defects will be apparent during test following final assembly. Even in such a case some additional inspection during receiving and shipping operations would be desirable.

When accurate statistics regarding defective workmanship have been compiled over a sufficient period of time, it is possible to forecast the degree of inspection considered necessary through mathematical analysis, using established principles of *statistical quality control.*[5] When accurate statistics are unavailable, it is logical to begin with slightly excess inspection, and to relax detail checking only as more becomes known regarding the points requiring continuance of detail inspection: those in which few rejections are experienced and in which small loss will result from occasional cases of defective workmanship.

The completeness and accuracy of the tooling used for manu-

[5] See Grant, E. L., "Statistical Quality Control," McGraw-Hill Book Company, Inc., New York, 1946.

facturing has great influence upon the degree of inspection necessary. The farther basic manufacturing operations depart from job-shop work and approach high-production methods, involving hard dies and substantial jigs and fixtures, the farther the inspection plan may safely depart from 100 per cent inspection of every operation on each part.

Basic Inspection Actions

Irrespective of the degree of inspection employed, there are certain actions that are basic for all inspection operations. These are examination of all items submitted to inspection for review, followed by either *acceptance* or *rejection* of all the items or a portion of them.

Items found to be within the limits established by engineering drawings and other quality standards are accepted. Those which are not within these limits are rejected. The rejection action can take two courses: rejected items can be designated either for *rework* or for *salvage*.

Those which deviate from engineering requirements but which are obviously reworkable to limits are normally rejected to the originating group for rework. Items that cannot be reworked are held for salvage disposition.

Representatives of Inspection and Engineering (and sometimes the customer) examine items held for salvage disposition. Three courses of action are possible: the items can be scrapped, they can be used without rework, or a special rework procedure can be devised. Usage of the items requires unanimous agreement of the salvage committee, and all salvage items are identified by special markings. Inspection should have full authority to scrap items considered unsuitable, irrespective of the viewpoints of other members of the salvage committee. The prerogative should be vested in Inspection, in order that responsibility can be accepted by this department for maintaining product integrity.

Inspection Tags and Stamps

A record should be maintained of all inspection examinations. A common procedure involves use of tags to identify the disposi-

tion of all items (or groups of identical items) presented to Inspection. Basic requirements for inspection tags involve "accepted," "rework," and "rejected" tags. These are usually of distinctive colors, to permit immediate identification; green, yellow, and red are frequently used to identify accepted, reworkable, and rejected items.

Frequently these tags are in multicopy or coupon form, to permit forwarding notification to the production-control department of all inspection action on each lot. This procedure is of considerable value in facilitating Production Control's task of maintaining a record of the flow of parts through fabrication and assembly operations.

If tags are not used, the production-shop order (describing the operations to be performed on the item) accompanying each lot may be stamped with an acceptance stamp when the items are found suitable. The stamp certifies that the items are ready for the next operation or for forwarding to stores. This procedure, of course, is feasible only when separate shop orders are issued for each production lot.

Acceptable items are forwarded to the next step in the production flow, and all defective items are retained for rework or salvage. The shop order and/or acceptance tags are noted, with the quantities of accepted and rejected items. When the bulk of the items are defective (but reworkable), it is sometimes customary to hold the entire lot, retaining the usable items in Inspection and forwarding the rework items to the department which must accomplish correction. In the case of a lot where a portion is rejected for salvage disposition, these are split off and sent to the salvage area for storage, and the remainder of the acceptable items are forwarded through production channels.

Inspection stamps showing the nature of the disposition and bearing a code number to identify the responsible inspector are normally used to mark tags, shop orders, and items. These are usually in the form of both metal and rubber stamps. A distinctive form (see Chap. 2) is normally used for each type of stamp, and a serial number used to identify the inspector to whom each set of stamps is assigned. Each inspector is supplied a set of stamps at the beginning of his employment and is held strictly

accountable for their whereabouts and usage. In many companies the penalty for unauthorized usage of inspection stamps is immediate termination of employment.

TYPICAL INSPECTION PLANS

The nature of an inspection operating plan can be more readily visualized by examination of plans used successfully by various industrial concerns. The following[6] have been selected as typical of those used by companies engaged in precision manufacturing and maintenance. In the case of operations with less exacting customer requirements, the detail requirements of the inspection plan should be reduced accordingly.

Magnesium Castings

Control of product quality begins with close supervision of the materials of manufacture. Ingot supplies are sampled and tested systematically. Both physical and chemical tests are used.

Owing to the fact that foundry scrap is remelted, it is necessary to sample and test each melt. When a heat is ready for pouring, a set of test bars are poured. These are identified by the heat serial number. One group is tested in the Inspection laboratory in the as-cast condition; a second group is processed through heat-treatment (with the castings poured from the heat) and then tested in the laboratory.

By this method, analysis, structure, porosity, and tensile and yield points are held to specification requirements. Castings cannot be released for shipment until approved by the Inspection laboratory.

Both the physical and chemical characteristics of magnesium are affected by the length of time the molten metal is held at elevated temperature. Also, specific castings require exact pouring temperatures. These factors necessitate close supervision and control, which is accomplished by time and temperature regulators connected to the furnaces. When conditions of melting have been satisfied, the control-room inspector releases the

[6] Certain of these plans are based upon descriptions appearing in "Construction and Production Analysis," prepared by the Air Technical Service Command, United States Air Forces. All are representative of specific companies.

melt. A public-address system is used to inform the pouring crew when a furnace is ready to draw.

Control of molding sand is maintained by sampling at the mullers every two hours, and instructions are issued regarding the nature and quantity of ingredients to be added. Changes of molding-sand content cannot be made without Inspection-laboratory approval.

First inspection of castings takes place following shakeout from the sand. At this point, cold shuts, misrun, visible cracking, pitting, and "sink spots" are checked. All rejections are classified according to causes, and the scrap is returned for remelt.

An intermediate inspection is made following processing in the cleanup room. This is a visual inspection for cracks, handling damage, and surface defects.

After final cleaning, the castings are given a final inspection, to verify wall thickness and dimensional accuracy. If X-ray inspection is required, the percentage of castings to be examined are sent to the X-ray laboratory, and the balance of the lot held until receipt of X-ray approval. Following this, the castings are either packed for shipment or rejected. All rejects are thoroughly examined for salvage.

When required by the customer, spot facing and locating points are machined on the castings or rough machining is performed, as required. These castings are inspected for dimensional accuracy prior to shipment.

A majority of the examinations are routine in nature, but procedures, controls, and limits are exacting. Inspection is responsible to the general manager and is not influenced by the production department.

Close controls and thorough examination of cause for defects often reveal the need for processing improvements. Over a period of 4 years, this has contributed to reducing rejections from a high of 40 per cent to an average of 12 per cent.

An interesting trend observed with rejections was a characteristic increase during the summer months. Inspection analyzed rejections for the cause of this seasonal increase and assigned as the major causes the drying effects of green-sand molds and surface pitting due to oxidation. Rapid drying of mold sections and

cores during hot weather caused loose sand to accumulate in the mold cavity. This resulted in sand inclusions in the completed castings. Rapid formation of magnesium oxide caused surface pitting and internal oxide inclusions sufficient to result in some rejections.

The inspection department subsequently assisted in developing a green-sand spray method to reduce the drying effect and

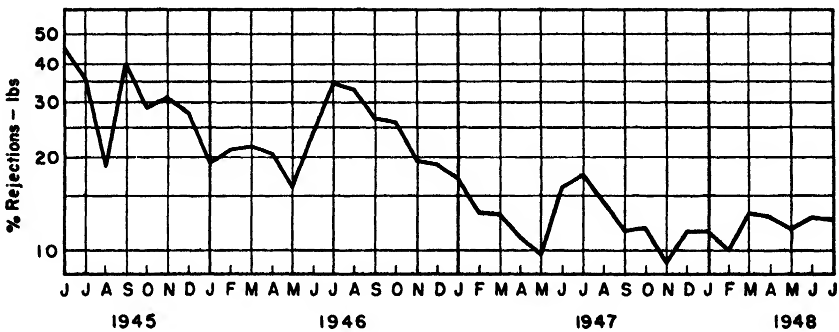


FIG. 1:2. Reduction in rejection of castings during four-year period.

corresponding loss of castings caused by sand inclusions. The reduction in rejections over a period of 4 years, largely attributable to intensive Inspection analysis, is shown at Fig. 1:2.

Aircraft Landing Gears

Inspection control is maintained by the use of routing tags and record sheets, which accompany all items during manufacturing operations. Inspection records must be properly stamped at each inspection station on the production line before additional processing can be accomplished. This is checked by inspectors on all items coming into the production departments.

Receiving inspection on all incoming material and subcontracted items is conducted in an enclosed, restricted area. A 100 per cent visual and dimensional inspection is accomplished on a majority of items that do not receive source inspection. A spot-check control is maintained on small items, such as nuts, bolts, and washers, and on parts that are source inspected. Affidavits are required to cover physical and chemical properties of all in-

coming raw-stock material that is not source inspected. The Inspection laboratory spot-checks warranted material for conformance with the affidavits.

Shock Absorbers

The product is a precision article and requires a high degree of inspection. Intensive inspection is further necessitated by low skill of workers and supervisors. Inspectors are assigned to handle first-piece inspection, as well as to spot-check all machining and processing operations.

A statistical quality-control system checks critical operations. Whenever results are outside the established limits, steps are taken to locate and correct the cause. This system has given good results and recurring errors have been gradually eliminated.

For inspection of work performed inside and outside the factory, definite written procedures and standards are followed.

The inspection department is well equipped with measuring and test instruments. A final test of completed end items is observed by two inspectors, one representing the company and the other the customer. The latter accepts the end item if it is satisfactory. When a diversified opinion arises as to quality or correctness of any item, a salvage committee decides the final disposition. All items purchased as finished units pass through the inspection department. Inspectors check all operations required for machining, heat-treatment, and electroplating.

Radio Transmitters and Receivers

Product quality is maintained by the following plan at the aircraft radio plants of Bendix Aviation Corporation.[7]

> As far as fabrication of parts is concerned, quality control stems back to . . . [an inspection flow record] card. (A card is established for each part number.) This . . . [shows] the number of accepted pieces produced by each operator listed, and the number of rejects. This card is stamped by the inspector in the presence of the worker concerned when he clocks off. As it shows the worker how many good and rejected pieces

[7] Summarized from Bartholomaei, H. A., "Records Keep Everybody Quality Conscious," *Wings*, December, 1944, pp. 1313–1318.

he is credited with, it keeps him quality conscious, as he knows the record is considered in figuring his bonus.

Inspection of incoming material, parts, and units is performed on a sampling basis, sampling tables being effectively used to safeguard the quality of purchased items at a minimum inspection cost.

Floor inspectors do not count parts accepted, but when a run is finished and the machine operator clocks off, he reports to the inspector, who counts rejects and assigns the reasons for rejections, enters them on the . . . [record] card, labels rejects and sees that they are not mixed with parts that have passed inspection. Later, a counter checks the number of accepted parts and enters it on the . . . card for record purposes, the count being checked ultimately at . . . [a central] inspection [area], through which pass all parts coming from machines.

Floor inspectors make a daily report . . . which is a summary of their day's work and an analysis of the reasons for all rejects. This report goes to the quality-control supervisor who uses it in preparing his summary daily report of rejects in each department.

The percentage of rejects [in the central] . . . inspection [area] is far higher than on floor inspection. This is partly because floor inspection is, as a rule, only of the spot type, whereas, in . . . [central] inspection, more thorough methods are applied and, where rejects tend to run high or the parts are critical ones, 100 per cent of the parts may be checked. Floor inspectors are kept aware that [central] inspection is, in a sense, a check on their work. This has a salutary effect in tending to prevent laxity.

Much of the foregoing is applied chiefly in . . . [fabrication] departments. In subassembly and final assembly, where different sets of conditions apply, a different method is followed. Much of the work is done on a line basis. Floor inspectors are placed at intervals along the line where they check every unit for specific operations or for a given performance as it passes through their hands. If any operation has not been properly done and can be rectified, the unit is passed back to the individual responsible, to undergo this correction. If not correctable, the unit goes to salvage with an appropriate marking by the inspector.

Since . . . [inspectors] are not infallible, there are points along the line where more or less cumulative tests are made and electrical performance is checked. There are [also], of course, the usual vibration and final performance tests, which every major assembly . . . must pass.

In final assembly, as well as for some subassemblies, there is attached to each unit an inspection process card on which each inspection proc-

ess is listed. Inspectors are required to stamp this card in the O.K. column as each item listed is checked [if found satisfactory]. Following final inspection, every unit produced undergoes inspection for mechanical and electrical operation and any faults that are revealed are corrected before . . . [units] are finally released for shipment.

Electric Motors

The product is highly standardized, and a majority of workers and supervisors have been with the company for a considerable period. However, much of the operation is on a piecework basis, and a reasonable degree of inspection is necessary to avoid the possibility that some workers will sacrifice quality for quantity.

All incoming shipments of material and parts receive a general examination for proper quantities, absence of damage, and conformance to purchase-order requirements. More dependence is placed upon purchasing only from vendors of proved integrity than upon exhaustive receiving-inspection operations.

Inspection in the factory is divided into the following four broad classes, depending upon the nature of the manufacturing process: (1) detail fabrication, wherein an item passes from machine to machine before being completed, and a variety of items are produced on the same machines; (2) unit fabrication, wherein a given item is completed in a special automatic machine or in a group of such machines arranged for progressive, line-production flow; (3) subassembly operations, such as winding stators; and (4) final assembly.

Items produced through detail fabrication receive a complete examination in a central inspection area after all operations have been completed. Line inspectors make periodic spot checks at each machine during the various manufacturing operations, to avoid production of excessive scrap or rework parts, but check only the operation being performed rather than the complete item. All items checked by line inspectors receive an inspection stamp on or adjacent to the dimension or surface inspected. Items accepted in central inspection receive an inspection acceptance stamp. Some items are given 100 per cent inspection in central inspection, while others are checked on a sampling

basis. The degree is based upon the importance of the item to successful functioning of the motor and upon the expense of its replacement, in the event of failure during subsequent assembly testing or service life.

Unit-fabricated items receive final acceptance inspection from a floor inspector assigned to the machine (or machine line) producing the item. All satisfactory items receive the inspector's acceptance stamp and are forwarded to stores to await withdrawal for assembly.

Subassemblies receive a visual examination for completeness and workmanship. Some, such as stator windings, receive an electrical test for correctness of connections, proper number of turns in each coil, and freedom from grounds. Accepted subassemblies ordinarily do not receive acceptance stamping, but are simply placed in the inspection outgoing (acceptance) area. Rejected subassemblies, however, are individually identified by rejection tags and are forwarded to the central salvage area.

Upon completion of all assembly work, each motor is given a run-in test, to check for noisy operation, excessive current consumption, oil leaks, or other obvious evidences of malfunction. Motors provided with integral speed reducers are also tested under full load with a dynamometer, for evidence of noisy bearings or gears. All motors accepted by final inspection receive an acceptance stamp on the identification plate.

An inspection flow report is prepared for each lot of a given item released by production control. This is completed by the inspector (or inspectors) examining the items, with notations of quantities accepted, reworked, and rejected at each inspection station involved. The clock numbers of the machine operators working on the lot are also noted. Upon the items being forwarded to stores, the flow report is forwarded to the inspection office for the transcribing of data pertinent to quality-control records, and thence to Production Control as a parts-count record.

Rework and rejection tags are used to identify all items returned for rework or forwarded to salvage for disposition. Rejected items are examined in the salvage area by representatives of Inspection and Engineering, to determine whether a special repair is justified or whether the items should be scrapped. A

coupon on the rejection tag is filled out and forwarded to Production Control, as notification on all scrapped items.

Ship Repair

Probably one of the most simple inspection plans is that followed by a Pacific Coast shipyard specializing in repair work for the tuna fleet. All purchased items and materials pass through receiving inspection, to ascertain conformance with purchase orders and absence of damage. Journeymen employed in ship repair are accountable to their foremen for the quality and completeness of work performed and are, in turn, responsible for the work of helpers and apprentices assigned to them.

Acceptance inspection during and upon completion of the work is solely the responsibility of the customer. The captain or the chief engineer of the vessel is on hand at all times during the repair work, and it must be accomplished to their satisfaction. Lines, wiring and plumbing diagrams, and basic structural-repair data are supplied by the company loft and engineering departments as required.

SELECTING A PLAN

The operating plan will be influenced to a major degree by the standard of quality considered necessary, and this is controlled by the end use of the product. For instance, a shock absorber considered of good quality for automotive use might be completely unacceptable for aircraft application.

The quality standards feasible for being maintained for a specified product in a given factory are affected by product design, average skill of workmen, caliber of supervisors, condition of production equipment, status of the facility itself (*i.e.*, vibration, dust, temperature and humidity variations, and the like), and accuracy of measuring instruments. Only when all variables are maintained within established limits is it practicable to control the quality of the end product.

Selection of the basic inspection plan should be a cooperative effort of Inspection, Engineering, Manufacturing, and Sales. The degree of quality practicable of being maintained under existing operating conditions, the percentage of defective items that can

be tolerated by company and customer, and the inspection cost that can be accepted must be considered. This last factor is extremely important, as product quality distinctly influences manufacturing costs and, consequently, the minimum selling price. High quality normally results in higher manufacturing costs. Lowering quality standards normally results in lower manufacturing costs, but introduces the possibility of customer dissatisfaction and loss of sales. This may result in greater cost to the company than that required to maintain higher quality standards.

When very large production quantities are manufactured over a considerable period, it is possible to maintain high quality standards without excessive costs. Semiautomatic inspection equipment, similar to the multiple gage in Fig. 1:3, is then economical, as the production quantity is sufficient to justify the gage cost.

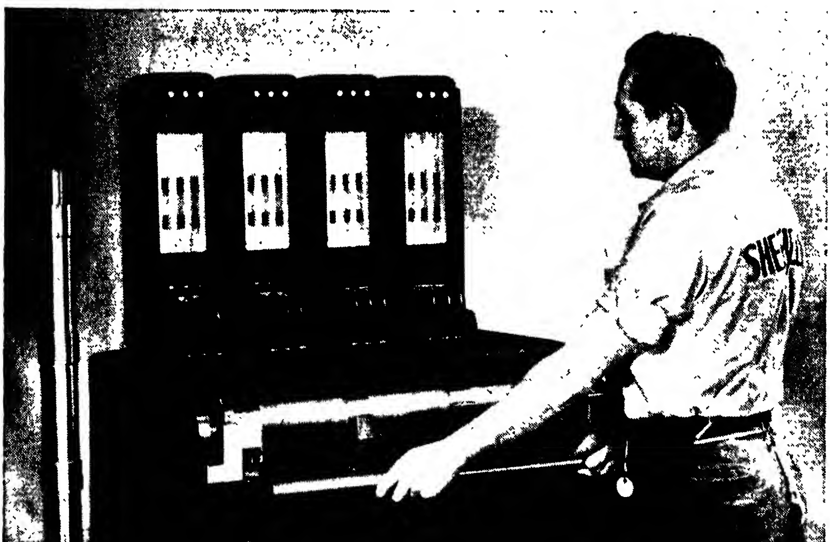


FIG. 1:3. Multiple gage for simultaneously checking several critical dimensions. (*Courtesy of The Sheffield Corporation.*)

Once the required quality standards are agreed upon, it becomes practicable to develop a detail plan for operation of the inspection department. Locations in the production flow where inspection is necessary can be determined, as well as the examinations required at each point. This permits determination of the inspection equipment that must be provided and the records of inspection flow that are necessary.

BASIC OPERATING PLANS

There are two basic operating plans for inspection control of quality. One is particularly well suited to job-shop and low-production operations. The other is suitable for extended manufacture of identical items at high-production rates.

It is common practice in job-shop and low-production operations for each lot of parts or assemblies to be accompanied by a shop-order traveler (released by the production-control department, to authorize manufacture of the particular lot), listing operations to be performed and indicating all inspection points. The inspector at each inspection point places a stamp opposite each inspection entry when examination of the items is completed and notes on the traveler the quantities received, accepted, rejected, and forwarded. Rejection tags are used to identify defective items found unsuited to rework.

An inspection flow record may also be maintained by each inspector for the benefit of quality-control statistical records. This lists quantities received, accepted, returned for rework, and rejected, according to part number and shift.

When the production flow is continuous without change for long periods, it often will be found that shop-order travelers are not required, although a reference copy of the manufacturing instructions may be posted at each work station. Instead of separate shop orders, Inspection uses "accepted," "rework," and "rejected" tags to identify the condition of parts and assemblies. Operation inspection lists (see Chap. 2) can be used to eliminate need for accepted tags for assemblies. Groups of identical items in each classification are usually placed in containers for forwarding to the next operation. A single acceptance tag is sufficient for a full container of items, while separate rework and rejected

tags are required for each group of items having a common defect.

With both plans, inspection "accepted" and "rejected" stamps may be applied to the items to indicate their status.

A modification of the second plan is necessary for high-production operations, where inspectors are stationed directly in the line of production flow. In these instances, accepted items need not be immediately identified by tags, but simply moved to the next operation by the inspector. Upon satisfactory completion of all operations, acceptance tags are applied to items or groups of items. Rework items are returned to the preceding operation for accomplishment of corrective action, accompanied by a tag stating the nature of the defect. Rejected items are tagged and forwarded to the salvage area.

Completed accepted items may be forwarded to the next station in the production flow or to a parts stockroom, depending upon the factory operating plan being based upon "free stock" or "controlled stock." In either case the department receiving the items signs the traveler or tag, to acknowledge receipt of the items, and this document is forwarded through the inspection office to Production-control records.

REQUIREMENTS OF AN INSPECTION PLAN

Considerable investigation and study must be devoted to the task if an entirely adequate inspection plan is developed. The final plan must be one that will satisfactorily maintain product quality at the required level without introducing unreasonable expense. Herbert Chase, in writing of planned inspection, outlines the following requirements for a complete inspection plan: [8]

> In essence, . . . [inspection] planning is quite simple. It requires:
>
> 1. Deciding where in the production . . . [flow] . . . inspection operations are necessary.
>
> 2. Making a definite record of each inspection operation needed at each inspection point or station.
>
> 3. Specifying precisely what gages and other inspection tools are needed.

[8] Chase, Herbert, "Planned Inspection Improves Quality Control," *Wings*, November, 1944, pp. 1276–1277.

4. Arranging that these tools are made available and are kept in condition.

5. Seeing that specific instructions are issued on proper application of inspection tools, together with any special precautions needed in performing the inspection operations.

Although the preparation of inspection specifications and precautions involves considerable initial paper work and some changes to keep the requirements up to date, the procedure has the advantage that the inspectors always know precisely what they must do and have access to needed equipment. Under . . . conditions where inspectors are scarce and . . . lacking in experience, specific standardized procedures are helpful.

Planned inspection . . . eliminate[s] unnecessary labor by preventing needless gaging and by providing the best gage for doing the job rapidly but precisely. As each inspector has a detailed and specific set of operations to perform, and they are listed in the correct sequence, he or she need waste no time in finding out what must be done or how to do it. The inspection equipment needed is always available when a new job is released, so there is no delay. Inspectors thus can spend more time on the actual work, and the chance that excess scrap may be produced before the inspector is ready is reduced. Inspectors shifted to new jobs or coming on a new shift learn instantly what they must do.

A part of planned inspection is the use of . . . [first-piece] inspection tags [or stamps]. Such tags are employed as records of first-piece inspection whenever machine operators are required to . . . [work to close dimensional limits]. First-piece inspection is required (*a*) on the first piece produced after a setup is completed to run a new lot; (*b*) on the first piece produced after a setup has been changed or modified, tools adjusted, reground, or replaced; (*c*) on the first piece produced after an operator is changed, whether on the same shift or on a new shift and whether the setup has been changed or not.

Under any of these conditions the machine operator must have the floor inspector check the first piece. If it passes the inspection, it receives . . . [a first-piece] inspection tag [or stamp] and this must remain on the first piece, which is kept displayed as long as the operator is on the job. Should the piece not pass inspection, the inspector may stop further production until suitable corrections are made.

PLANNING THE WORK FLOW

The inspection plan should closely parallel the flow of production through its phases of receiving, fabrication, assembly,

and shipment for all items. When the flow of inspection work is being planned, it should be kept in mind that inspection is a *service* function. All service functions within a manufacturing organization should exist as direct aids to production. This does not mean that Inspection should be subservient to Production, but rather that Inspection must assist rather than hinder the flow of material through men and machines that forms the basic operating plan for Production. Only in this manner can maximum efficiency and minimum cost be realized. No case should be tolerated where service functions are served *by* Production. When this occurs, production flow is likely to falter, or even to cease.

In Fig. 1:4(*a*) is seen a case where fundamental production principles have been violated through choice of an undesirable inspection plan. A fence has been placed around the inspection area. Production must come to this area with its completed items. These are inspected and then released to Production when

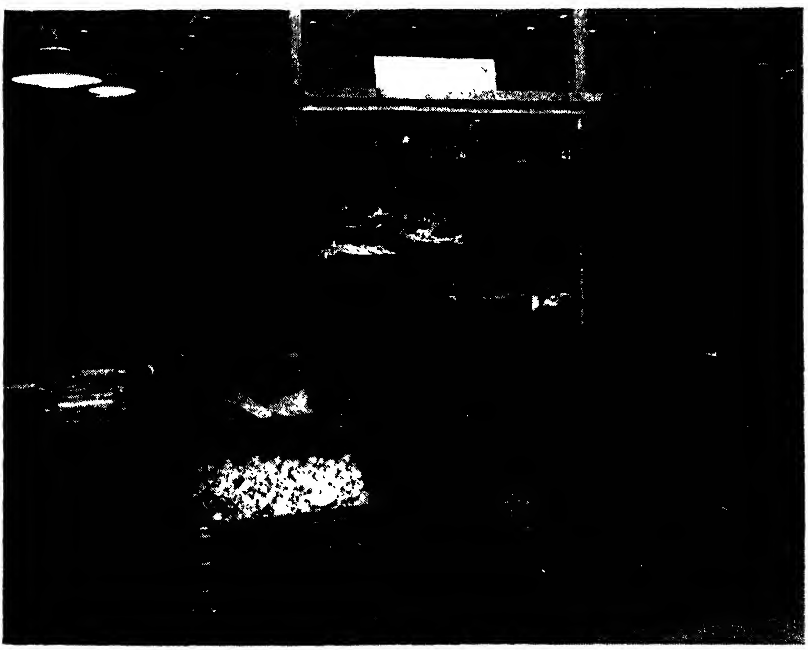


Fig. 1:4(*a*). This enclosed inspection area effectively restricts production flow.

FIG. 1:4(*b*). The inspection function is now part of production flow. (*Courtesy of Consolidated Vultee Aircraft Corporation.*)

and where Inspection pleases. The first fundamental of production flow has been defeated. Instead of serving Production, Inspection is being served. By removing fences and other obstacles, Inspection becomes part of production flow, as seen in Fig. 1:4 (*b*). It now provides a *direct* service.

CHAPTER 2
OPERATION

The inspection plan of operation should closely parallel the flow of production through receiving, fabrication, assembly, and shipment. Normal receiving and shop "paper" should be used for checking and recording Inspection action. In no case is it desirable to establish parallel Inspection records based exclusively upon "paper" created by the inspection department. It is a prerequisite for efficient manufacturing that all factory personnel work in accordance with identical orders and records. Misunderstandings, errors, and unnecessary work result when each department creates its own records.

SOURCES OF INSPECTION INFORMATION

Inspection should maintain product quality at the required level in accordance with standards supplied by Engineering and the customer. It is not a proper function of Inspection to establish such standards, but rather to interpret and apply these data to develop a plan for examination of materials, items, and end items.

All production materials received from outside sources should be examined upon receipt to verify conformance with relevant purchase orders. Inspection should receive copies of each purchase order immediately upon issuance, so that these will be in receiving inspection files when the corresponding items arrive.

The purchase order and the packing sheet accompanying the shipment provide all basic data required for inspection of incoming material. Quantities, conformance to description, and special requirements can be verified. Without both of these documents, accurate receiving inspection becomes difficult. Many inspection departments follow a practice of immediately rejecting all shipments which are received without packing sheets,

or for which copies of the purchase order have not been received. In such cases the rejected shipment is held in the salvage area, awaiting disposition information from the purchasing department.

Engineering Data

Manufactured articles are normally built in conformance with drawings prepared by the company's engineering department. Copies or prints of these drawings are the basic data used by Inspection to check dimensional accuracy and completeness of items. Normal procedure involves forwarding to the inspection-department files one or more copies of each new and changed drawing. These are used for reference when checking items, and provide the prime criterion for acceptance or rejection of work.

Engineering may also supply various specifications to supplement data shown on drawings. A specification frequently encountered is a "model specification" providing a detail description of the construction of the completed end item, together with listings of mandatory equipment requirements and minimum performance standards. Other specifications may be issued to describe special manufacturing processes, and functional tests may be required during and after assembly of the end item. These provide additional quality requirements impracticable for specifying on drawings and criteria for controlling vital manufacturing processes.

Production Data

Shop orders (sometimes referred to as "work orders," "operation sheets," or "production orders") are normally prepared by the manufacturing planning department to describe all operations required for a given item. These are released to the factory by Production Control as authorization for manufacture, after addition of data showing lot number, quantity required, and in-work and completion dates. Similar orders, termed "assembly orders," are issued to authorize and describe assembly operations.

These orders serve as the basis for orderly handling of inspec-

tion; providing a listing of manufacturing requirements and a record of all inspection accomplished on the items.

Changes in Manufacturing Requirements

Changes in manufacturing requirements are undesirable but equally unavoidable. It is impossible to foresee all conditions that will be encountered during manufacture of a product, and production-improvement changes will be discovered during fabrication and assembly of the end item. Other changes originate from engineering errors during initial preparation of drawings. Unsatisfactory operating conditions experienced by customers often require design changes, and in the case of contracted articles the customer's requirements may alter during the life of the contract.

Information regarding these changes reaches Inspection in the form of purchase-order change notices, prints of changed versions of drawings, copies of advance drawing-change documents,[1] and as specification revisions. In a majority of cases these changes are effective on the start of a designated production lot, or on a specified serial number of completed end items. It is Inspection's responsibility to verify that the stipulated changes actually take effect upon designated lots or serial numbers, and to reject for rework items that do not incorporate required changes.

Effective, accurate Inspection handling of changes in manufacturing requirements can become a routine matter when proper attention is given to establishing a logical change-control system. The elements of a successful system require that copies of all change information be routed to a control point in the inspection office for classifying, recording, and forwarding to inspectors. Copies of change notices, advance drawing changes, and specification revisions should be promptly attached to the affected documents. This cannot safely be left to the discretion of individual inspectors, but should be accomplished by the change-control representative in the inspection office. Duplicate

[1] See Thompson, James E., "Engineering Organization and Methods," pp. 216–226, McGraw-Hill Book Company, Inc., New York, 1947.

reference copies of all change documents should be supplied to inspectors responsible for verifying change incorporation.

Control of Data

All inspection data should be filed and recorded in an orderly manner. This requires that suitable files be established for purchase orders, drawing prints,[2] specifications, and advance drawing changes. Maintenance of these files should be made the specific responsibility of one person, and Inspection personnel desiring the loan of data should always obtain the required documents from the person in charge of the files. Unless this is done the data may become misplaced or destroyed, and there is constant danger of working from obsolete information.

Each piece of inspection data should bear a serial number, and a record should be maintained of all documents loaned from the files. The file clerk should be responsible for maintaining all data in an up-to-date condition by promptly attaching copies of change documents. The file clerk should personally notify affected inspectors of the receipt of a later change version of any data. Even though the new version may not be applicable to the particular lot of items being checked by the inspector, it is preferable to provide notification of *all* changes than to risk failure to provide data on important revisions to manufacturing requirements.

APPLYING THE INSPECTION PLAN

A practicable inspection plan must closely parallel the flow of production work. The application of a plan based on this concept establishes the general activities of Inspection as a service to the production flow, beginning with receipt of material on company premises through shipment of end items to the customer.

Receiving Inspection

Receiving inspection is normally responsible for examination of all raw-stock materials, manufactured items, and tooling purchased by the company for use in production activities. Inspec-

[2] *Ibid.,* Chap. 10, for detail information regarding print filing and control.

tion's prime responsibility is determining whether these items meet all requirements established by purchase orders, are in proper working condition, and are free from damage.

Closely allied with this activity is outside production inspection, responsible for maintaining quality at factories engaged in manufacturing parts to company designs. This involves main-

FIG. 2:1. Receiving inspection department in modern aircraft company. (*Courtesy of Consolidated Vultee Aircraft Corporation.*)

taining liaison with outside production sources to determine whether inspection methods and standards at the outside production sources are adequate to provide the required quality, and to insure that rejections normally take place within the outside producer's plant, rather than in the company's receiving department.

When highly stressed precision units are manufactured, there is generally need for magnetic-inspection operations. These begin with receiving inspection—where the necessary equipment should be available. In a small company it may be that the only magnetic-inspection equipment will be in Receiving, and machined and welded items will be forwarded from other factory areas for additional magnetic inspection. In larger plants additional magnetic-inspection equipment will be located in inspection areas adjacent to the machine-shop and welding departments.

In any event there will be required machines, instruments, grinding equipment, electric power, and compressed-air sources adequate for properly conducting magnetic inspection on ferrous metal. Also, if and when it is found essential and justifiable, equipment may be added to provide for fluorescent-penetrant

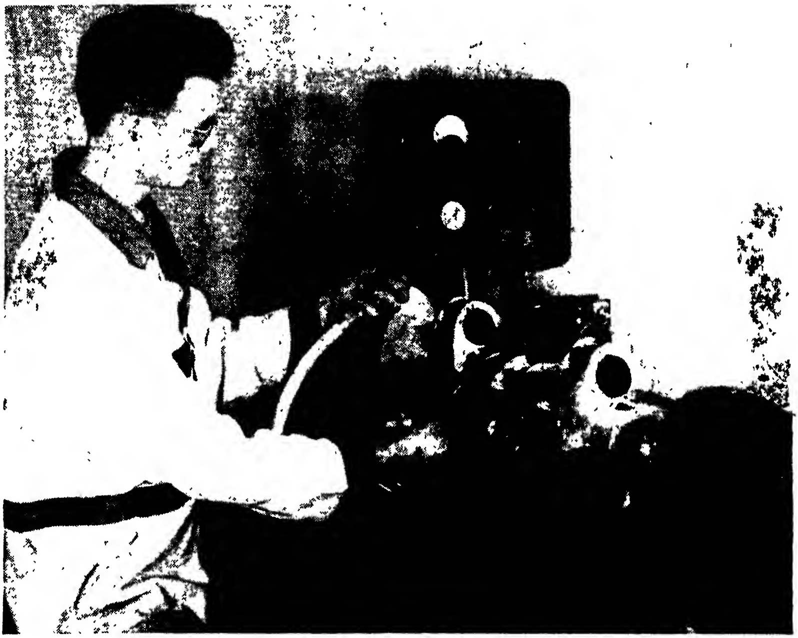


FIG. 2:2. Magnetic inspection of crankshaft. (*Courtesy of Magnaflux Corporation.*)

and/or radiographic inspection on nonferrous metals. (See Chaps. 7 through 10 for detail information on inspection equipment.)

Magnetic inspection's function is determining (through magnetizing items fabricated from ferrous metals while coated with a magnetic powder or fluid) the presence or absence of cracks, inclusions, laps, seams, or other defects that might adversely affect strength. A similar indication can be obtained through use of the fluorescent-penetrant method for nonferrous metals that will not respond to magnetic treatment.

Fabrication Inspection

This activity of Inspection is directly associated with the preparation, forming, machining, and processing of raw-stock material into detail items, prior to their entry into stores or assembly operations. The work of this arm of Inspection applies mainly to metal and its preparation, although for the sake of grouping related activities, some minor bench-assembly work is often placed under the jurisdiction of fabrication inspection.

All inspectors in departments using machines such as routers, shears, presses, drop hammers, woodworking equipment, machine-shop tools, welding apparatus, and the like are part of the fabrication-inspection function. In view of the fact that such processing operations as heat-treatment, sand blasting, electroplating, anodizing, and painting are more frequently encountered in fabrication, these activities are usually the responsibility of fabrication inspection. In general, fabrication inspection is responsible for the quality of detail items from the time raw-stock material is withdrawn from stores until the detail items are completed.

Assembly Inspection

Assembly inspection applies to any operation of joining two or more detail items into a unit for incorporation into the end item. Generally the items used to form assemblies are obtained from detail parts stores, an activity which either actually or technically supplies items to the assembly departments.

All items used in assembly operations should have been accepted by preceding inspection during fabrication. The prime responsibilities of assembly inspection involve verifying fabrication-inspection acceptance and ascertaining that all assembly operations are properly accomplished, with the specified items connected in the required manner.

Shipping Inspection

Items delivered to the shipping department usually have been inspected and accepted by one or more fabrication or assembly

departments. The primary responsibility of shipping inspection is to determine that items delivered to Shipping comply with and are complete according to all data listed on the sales order.

Further, all shipments must be checked for correctness of packing in the proper containers, to insure against damage in transit. Shipments must be marked with all data as listed on the sales order and the packing sheet. As in other inspection activities, items found incorrect or incomplete are returned to the proper departments for correction or rejected for salvage action.

Tooling Inspection

All tooling used for manufacturing should be checked by Inspection prior to release for use by the factory departments. It may be claimed that the tool-manufacturing department should check its own work, but the argument is illogical. It is generally recognized as a basic principle of quality control that the activity responsible for accomplishing a given operation should not have the responsibility of inspecting that work. Irrespective of the integrity of the activity in question, it is impracticable for them to check their own work, owing to the ever-present tendency to "read into the work what it should be, rather than what it actually is." Inspection is responsible for accepting the items produced by production tools and should have the opportunity of checking and approving these tools prior to usage.

In general, the tooling activities of Inspection involve examination of all completed production tools, tryout, and proofing, as necessary, and periodical reexamination of tooling during production usage. All purchased tooling should be inspected upon receipt. Tooling should be accepted or rejected on the basis of ability to produce acceptable parts under normal operating conditions. Usage of all precision gages and instruments also should be authorized by the tooling section of Inspection.

CUSTOMER INSPECTION

In certain cases, particularly with government contracts, the customer may require that final acceptance of each end item and any item thereof be subject to approval by customer inspectors assigned to the manufacturer's plant. In theory this

means that all items are reexamined by the customer's Inspection and may be rejected, should it be found that any quality requirement has been neglected.

Obviously this would require almost complete duplication of company inspection personnel and equipment on the part of the customer, and its strict application is usually considered unfeasible. In actual practice the customer's Inspection usually concentrates on verifying the soundness of the manufacturer's inspection plan and the accuracy of its operation. Once these are determined to be satisfactory, the manufacturer is granted an "approved" inspection rating, and customer inspectors concentrate upon acceptance examinations of completed end items; with occasional spot checking of incoming material, critical items, manufacturing methods, and processes. All salvage acceptance action usually is subject to final approval by the customer's Inspection.

CONTROLLING THE WORK FLOW

A prerequisite to controlling the flow of any production work is establishing positive identity for each lot of items processed through the manufacturing cycle. Production procedure usually involves issuance of a *shop order* (see Fig. 2:4) to authorize work on each lot of every item passing through fabrication and bench-assembly operations. Similar authorizations termed *assembly orders* (see Fig. 2:5) and *installation orders* are issued to control primary and final assembly work. These are prepared by Manufacturing Planning and issued by Production Control as necessary to maintain the required manufacturing schedules.

These orders, issued as manufacturing authorization and instructions, provide a positive means of recording all work accomplished by Inspection and of controlling the flow of work through the various inspection stations. Each shop order bears a "lot number" for positively identifying each production lot of a particular part. This provides a means of establishing controls in fabrication and bench-assembly departments, wherein the serial numbers of the completed end items that will receive the detail items cannot be ascertained by any practicable means.

During final assembly operations, each completed end item is

normally identified by a serial number, and this can be used to provide positive identification, in cases where the daily production output is moderate. When there are large outputs (especially in the case of small items), end-item serial numbers may not be used, and it becomes more logical to continue the production "lot-number" identification system throughout the manufacturing cycle.[3] In the case of primary assembly operations (where detail items and small assemblies are joined to form major assemblies, which in turn will be joined to complete the end item), it is feasible to use either lot numbers or end-item serial numbers. The choice will depend upon the feasibility of establishing the equivalent end-item serial numbers during the primary assembly operations.

In a majority of cases (except with high-rate production of identical items) it is feasible to use production lot numbers to identify each group of items passing through the fabrication and bench-assembly departments. Lot numbers and/or end-item serial numbers can ordinarily be used to identify assemblies during primary and final assembly. Purchase-order and sales-order numbers provide equally positive control for items reviewed by Inspection in the receiving and shipping departments.

Inspection Flow Record

A basic document used for recording the flow of inspection work is the *inspection flow record* (see Fig. 2:3). This is simply a listing of all items examined during each shift by a particular inspection station, and it provides for the following information, as required:

Date. Date covered by record
Shift. Shift covered by record
Dept. Name and No. Location of inspection station preparing the record
Purchase Order or Part No. Numerical identification of item
Description. Name or description of item
Seq. Release (lot) number (shown on shop or assembly order) is entered here

[3] In the case of very high production rates, lot identification and reissuance of identical shop and assembly orders are not necessary (see pages 22 and 23).

Total Quantity. Total quantity of items received and examined by inspector
Accepted. Quantity of items accepted
Rejected. Quantity of items rejected
W. O. Shop- or assembly-order serial number, when applicable
Sub. Dept. Departments to which accepted items were forwarded by Inspection
Remarks. Pertinent information relating to rejected items, including rejection-notice serial number
Signed. Signature of inspector preparing record

DAILY INSPECTION REPORT

Date ____________

Shift ____________ Dept. Name ____________ Dept. No. ____________

Purch Order or Part No	DESCRIPTION	Seq	Total Quantity	Accepted	Rejected	W. O.	Sub Dept.	REMARKS

Signed ____________ Inspector

FIG. 2:3. Typical inspection flow record.

When the inspection flow record is prepared by each inspection station for all completed items passing through that station, complete information on all inspection action is available to everyone affected by the production flow. Production Control will be informed of accepted and rejected quantities on each item (especially valuable when separate shop orders and a "lot" release plan are not used) and can issue supplemental orders to

prevent shortages. Accounting will have daily production-count data for operation of a standard cost system. Engineering can investigate cases of unusual rejections to ascertain whether the design is unnecessarily difficult to manufacture. Inspection has data usable in establishing quality-control statistics.

The completed inspection flow record from each inspection station should be forwarded to the Inspection office at the close of each shift, as a record of the daily completed work accomplished in the factory. Intermediate operations are not listed on the flow record, only completed items. The shop order, which lists each operation involved in making a given item, serves as a record of Inspection acceptance of intermediate operations.

Shop Order

The shop order issued to authorize manufacture of a particular lot of items should be used as the record of Inspection action on each operation involved in their fabrication or bench assembly. This is readily accomplished when the shop order lists each operation required to produce the item, and provides a column or columns for Inspection notations and stampings. See Fig. 2:4 for an example of a shop order arranged to provide for both production and inspection usage.

Inspection reviews each shop order prior to examination of the items, to ascertain that all required preceding inspections have been "stamped off," and that the operations for which the items are now presented for inspection are in accordance with the order and with all applicable drawings and specifications.

An accurate count should be made of the items, and this quantity should be compared with that specified on the order. If some of the items have been rejected on preceding examinations, the actual quantity will be less than that specified on the order. Following count and inspection, the quantities received, accepted, and rejected are noted on the order.

After all inspection work is completed, the inspector places an acceptance stamp at the side of the inspection operation entry, prior to forwarding the accepted items to the next operation. Items requiring rework are segregated and a rework tag noting the required action is attached. The rework items are returned

TRAVELER					TRAVELER		
PART NO. 58416	CH. LET /	NO. E.I. 10	NO PIECES THIS ORDER: L H	R.H	N. 20	DATE ISSUED 2/25/49	RELEASE 1	I W 132 / C 138
INDEX NO. 6-3145	PAGE 1	OF 1	SPLIT BY			MODEL A-6	CONTRACT 156	ACCOUNT 1121
PART NAME END-HYD CYL PISTON ROD						ARMY ☐	NAVY ☐	COMM. ☒
NEXT ASSEMBLY 58419						QUANTITY ENTERING INSPECTION: L H	R H	N
PLANNER SMITH	QUANTITY PER E.I.: L H	R H	N 2	M.C. NO.	THIS PART EFF ON 1 THRU UP	THIS COPY USED ON	THRU	

OP NO	DEPT.	OPER.	QTY ACCEPTED L H	R H	N.	DATE	CO	CUST	QTY REJECTED L H	R H	N	MACH CODE	TOOL NO.	TOOL NAME	TOOL DEPT
1	6	Issue material													
2	1	Turn, Form, Face												TL	
3		(allow 0.625 dia at cutoff)													
4		Centerdrill, drill, countersink &													
5		Tap 3/4-16													
6		Cutoff & Finish spherical radius													
7		Straddle-mill 0.452 & 0.875 dim. & Mill 7/32 dim.												HM	
8		Drill & Ream 1.062 dia &												TL	
9		Undercut oil groove													
10		Drill no. 44 (0.086) dia, Counterdrill													
11		Countersink & Tap 1/4-28													
12		XLO Bore to size												XLO	
13	4	Wash													
14	1	Burr & stamp part no.													
15	5	Insp													
16	4	Cad plate													
17	5	Insp													
18	5	Insp											Magnetic		
19	10	Store													
20															
21															
22															
23															
24															
25															

E.I. QUAN THIS PART	MATERIAL	R	C	E	QTY DELETED	UNIT PRICE	TOTAL
2	1-3/4 dia x 4-1/8						
	4130 CM Stl Bar, Normalized	x					
	Allow for chucking						

NO. PCS RECEIVED	L H.	R.H	N.	BY STOCKROOM NO	CLERK'S CLOCK NO	DATE

FIG. 2:4. Typical shop order.

to the erring department for accomplishment of the required correction, and the accepted parts are held for return of the reworks. Upon completion of acceptable rework, the lot of accepted items is forwarded to a production-control dispatcher. If the rework will require considerable time, the lot may be split by Production Control and the accepted items be forwarded immediately. When a very high production of identical items is involved, and shop orders are not issued on a "lot" basis, acceptable items are immediately forwarded in every case.

As for rejected items, these are split off from the production lot, identified by a *rejection notice,* and forwarded to the salvage-inspection area. The accepted items (accompanied by the shop order) are forwarded to stores or to the next operation, as the case may be.

Following completion and Inspection acceptance of all operations, the items are ready for forwarding to stores. The intermediate operational inspection has probably been accomplished, either by floor inspectors assigned to certain areas or by an inspection station in each department involved with manufacture of the item.

Before the items are finally accepted, it is sometimes considered desirable to provide an additional examination. This is sometimes termed "control" inspection and involves passing the items through a central inspection area for verification that all operations have been properly completed and certified. At this time an additional 100 per cent inspection of a few items in each lot will usually be made as a check on the accuracy of operational inspection. Upon acceptance by control inspection, the items are individually marked with an Inspection acceptance stamp, when size and material permit.

Assembly Order

Large assemblies are often released in lots but, owing to their bulk and to the time required for completion, are rarely presented to Inspection in lots. The usual practice is to call for inspection upon completion of each assembly. This is not, however, the usual case with small bench assemblies, which are normally handled in the same manner as detail items.

It is practicable to use the *assembly order* (which is simply a shop order specifying assembly operations, rather than fabrication information) to record inspection of each assembly. At such time as the first assembly is completed and accepted, the inspector can note "1st assembly accepted," in ink on the reverse side of the corresponding assembly order, and place an acceptance stamp beside the notation. This procedure can be repeated on each succeeding assembly required by the order, until the final item has been accepted.

TRAVELER **TRAVELER**

PART NO.	CH. LET	NO. E. I.	NO PIECES THIS ORDER L.H.	R.H.	N.	DATE ISSUED	RELEASE	
58419	B	10			20	2/25/49	1	I W 140 / C 145

INDEX NO. 6-3157	PAGE 1 OF 1	SPLIT BY	MODEL	CONTRACT	ACCOUNT
PART NAME END ASSEM-HYD CYL PISTON ROD			A-6	156	1121

ARMY ☐ NAVY ☐ COMM. ☒

QUANTITY ENTERING INSPECTION: L.H. | R.H. | N.

NEXT ASSEMBLY 58033

PLANNER	QUANTITY PER E. I. L.H.	R.H.	N.	M. C. NO.
GREEN			2	THIS PART EFF. ON 1 THRU UP

THIS COPY USED ON · THRU

OP NO	DEPT.	OPER.	QTY ACCEPTED L.H.	R.H.	N.	DATE	CO	CUST.	QTY REJECTED L.H.	R.H.	N.	MACH CODE	TOOL NO.	TOOL NAME	TOOL DEPT
1	6	Issue material													
2	9	Assemble and stake													
3	5	Insp													
4	10	Store													
5															
6															
7															
8															
9															
22															
23															
24															
25															

E. I. QUAN THIS PART	MATERIAL	R	C	E	QTY DELETED	UNIT PRICE	TOTAL
1	58416 End		X				
1	S2101-6 Fitting	X					
1	B-900H Bearing	X					

NO. PCS. RECEIVED	L.H.	R.H.	N.	BY STOCKROOM NO	CLERK'S CLOCK NO.	DATE

FIG. 2:5. Typical assembly order.

In the case of an order issued for a single assembly, a similar procedure can be followed. When the corresponding assembly is completed and accepted, the inspector should note "accepted" in ink on the order, list the date of acceptance, and place an acceptance stamp beside the entry.

This method of handling assembly orders is predicated on the assumption that the order form itself does not provide for individual acceptance entries for each assembly. This can be done, but it is not strictly necessary. When an assembly manufactured on an individual order is rejected, the rejection-notice (see Chap. 13) serial number should be listed on the assembly order opposite the operation where rejection or rework became necessary. A corresponding entry of the rejection serial number should appear on the inspection flow record of the inspection station ordering the rejection.

When a rework or rejected assembly is one of several comprising a lot covered by a single assembly order, notation regarding the rework or rejection should appear in ink on the back of the assembly order, similar to the procedure for noting acceptance of individual assemblies. Records of the assemblies should be arranged in numerical order, with all pertinent data grouped for each, similar to the following example:

1st ASSEM . . .	Rework—6/4/48 Accept—6/7/48	*Acceptance Stamp*
2d ASSEM . . .	Reject No. 1063—6/7/48	*Rejection Stamp*
	Salvage Accept—6/8/48	*Salvage Acceptance Stamp*
3d ASSEM . . .	Accept—6/7/48	*Acceptance Stamp*

Pertinent data, including assembly-identity, part number and rejection serial number, should be entered on the inspection flow record.

Inspection Call Board

When large assemblies are involved, it is often impractical to bring the completed work to an inspection area for examination. Instead, the inspector goes to the assembly and conducts the necessary examination in the factory department. Inspectors as-

signed to this type of work are often referred to as "floor" or "patrolling" inspectors, in contrast to those assigned to a given area, who are normally designated as "booth" or "crib" inspectors.

Each of the floor inspectors may serve a considerable area, and it is necessary to provide a convenient means of notifying the responsible floor inspector of work awaiting examination. In a small shop it would, of course, be feasible for the foreman desiring the inspection to locate an inspector. In large plants

INSPECTION CALL SHEET

	CALL NUMBER	END-ITEM NUMBER	INSPECTION REQUIRED	TIME CALLED	LEADMAN	TIME ON	INSP	NUMBER SQUAKS	NUMBER TAGS	TIME OFF	INSP
1											
2											
3											
4											
5											
6											
7											

FIG. 2:6. Inspection call sheet.

this is not always feasible, and an "Inspection call-board" system is frequently used to notify inspectors of work requiring examination.

Call boards, which are nothing more than small bulletin boards, are conveniently located in factory areas requiring on-site inspection. One or more boards are assigned to each floor inspector. A shop foreman desiring inspection action reports the item awaiting examination by entering on the *call sheet* (see Fig. 2:6) a description of the item, its location, the time of entry, and his signature.

Inspectors render the service requested on their call boards in the order listed on the call sheets. The inspector records the time when examination is started and completed, and certifies each entry with his stamp. When it is deemed necessary that certain calls be given priority over others, the factory general foreman should approve this action by notation on the call sheet.

Split Orders

It sometimes becomes necessary to split a quantity that has been authorized by a given work or assembly order into two or more smaller lots. This can occur for a variety of reasons, such as that a considerable portion of the lot requires lengthy rework operations. This may be an item that is on short supply and urgently needed to avoid assembly-line shortages. In such a case it is common practice to "split off" the defective parts from the original lot, letting the acceptable parts continue on through the production flow, while the defective parts remain for rework as a new lot. This requires that Production Control shall issue a new shop or assembly order, to identify the split portion of the lot.

When it is found necessary to split an order, the inspector in charge of the point where the lot is split should place an acceptance stamp on the new order opposite the last "accepted" operation indicated on the original order. This will certify that Inspection has reviewed and accepted the new lot up to the point of splitting into original and new lots. From that point on, each portion of the split lot is considered as a separate group, without reference to any other.

ASSEMBLY CONTROL FOR REPETITIVE PRODUCTION

In the case of job-shop operations, it is customary to issue separate orders for each assembly or for small lots of assemblies. When the operations become distinctly repetitive in nature—particularly in case of proved designs wherein engineering changes are comparatively few—the repetitive issuance of identical assembly orders would represent an illogical expenditure of time and material.

Assembly-station List

In such cases it is considered good practice to issue sets of assembly orders to the final-assembly line. These are often termed *assembly-station lists* (ASL). Each set contains all the orders required to describe the work accomplished at a particular line station for a specified model of end item. These are not replaced unless major changes occur or the model is discontinued.

Supplementary sheets, however, may be added from time to time to list minor changes or advance drawing changes that affect a particular model.

Operation Inspection List

When assembly-station lists are employed, it is no longer feasible for Inspection to use the assembly and installation orders as records of inspection action, and another document must be introduced. A common method is the issuance of *operation inspection lists* (see Fig. 2:7). These are simply indexes of the assembly and installation orders (ASL pages) to be accomplished as a particular line station for a given model. Both shop supervision and Inspection can stamp these off, order by order, as assembly progresses, to certify that the work has been properly accomplished. Rework and rejection tags are used to identify unsatisfactory conditions.

A separate operation inspection list is prepared for each end item and for every final assembly station through which the end item passes. These are filed by the Inspection office as each is completed. Upon an entire set's being accumulated for a given end item, there is positive documentary evidence of its complete inspection.

When this scheme is used, the assembly-station list provides instructions on what is to be done at each assembly station, and the operation inspection list provides a record of actual accomplishment.

This does not eliminate the need for final acceptance inspection and test of the end item, but it should reduce to a minimum errors found during final shakedown examination.

A typical *operation inspection list* is shown in Fig. 2:7. This provides for the following information:

Description. Drawing title or other description of assembly for which list has been prepared

Assembly No. Drawing number of assembly for which list has been prepared

Date. Date the list was issued

Supersedes Issue of. Date of issue superseded by revised list

Revised by. Name of person preparing list or revision

Model. End-item model to which list applies

End-item No. Serial number of end items to which list applies

Oper. No. Serial numbers of assembly-station list sections which describe the required assembly work

Eff. on. End-item serial number effectivity of each operation number. These may not always be the same, as production changes may introduce special operations relating to certain end items

Assignt. Used to indicate the inspector to whom the work is assigned.

Shop. Initialed by shop supervision when work is completed and ready for inspection

Insp. Inspection-acceptance stamp placed in this space when work is acceptable to Inspection

Cust. Space provided for customer's inspection-acceptance stamp, when end item requires approval by customer prior to delivery

OPERATION INSPECTION LIST

DESCRIPTION: *Jack Assem-Pump* ASSEMBLY NO.: *59700*

DATE	SUPERCEDES ISSUE OF	REVISED BY	MODEL	END-ITEM NO.
2/16/49	—	*Jones*	*C-123*	*73*

OPER NO.	EFF ON	ASSIGNT	SHOP	INSP	CUST	OPER NO.	EFF ON	ASSIGNT	SHOP	INSP	CUST
6-4123	*1 & up*										
6-4124	*1 & up*										
6-4125	*1 & up*										
6-4126	*1 & up*										
6-4127	*1 & up*										
6-9031	*80 & up*										
6-4128	*1 & up*										
6-4129	*1 thru 20*										
6-8263	*21 & up*										
6-4130	*1 & up*										
6-4131	*1 & up*										
6-4132	*1 & up*										

NEXT ASSEM	REMARKS:	DEPARTMENT	CC	STATION	SHEET / OF
59900		*16*	*2*	*3*	*1* / *1*

Fig. 2:7. Operation inspection list.

ASSEMBLY SHORTAGE RECORD

A smoothly operating production program is presumably free from shortages of parts required for assembly. Unfortunately this is not always the case, and shortages of certain parts may develop from time to time. Often the unavailable part is comparatively minor in nature and is one that can be installed at a later point in the assembly sequence. Under these circumstances it is obviously unfortunate to withhold a quantity of large assemblies while awaiting a single unavailable part.

The effect of assembly shortages upon production often is cumulative. Not only is it impossible to complete the assemblies where the shortage first develops, but the lack of these may prevent completion of the next assembly, and on through the sequence to the last assembly station. It is evident that some device is necessary to permit at least a portion of the incomplete assemblies to move on to the next assembly station.

An *assembly shortage record* (see Fig. 2:8) can be used for

ASSEMBLY SHORTAGE RECORD

SHEET OF

ASSEMBLY: ASSEM NO

DATE	DEPT	EFF ON END ITEM NO	MODEL	END ITEM NO	ITEM NO

INST NO	PART NO OF SHORTAGE	QUAN	STA	INSTALLATION TITLE	MECH	L MAN	INSP

ORIGINAL

Fig. 2:8. Assembly shortage record.

safely moving incomplete assemblies to the next production operation, provided that adequate control and follow-up are maintained to insure the shortages' being corrected before completion of the end item. This procedure should be used only in cases where holding the short assembly in the originating station will cause shortages in subsequent stations. It should never be used simply as an expeditious means of moving the assemblies—only when the need for the items at succeeding stations is critical.

A *shortage tag* (see Fig. 2:9) is securely attached to each "short" assembly, to provide rapid identification during subsequent routing. This should be attached with a positive means (such as a wire and lead seal), to minimize accidental removal.

The wire and seal are almost certain to remain as an indication of shortage, even though the tag has been accidentally removed. The Inspection "accepted" stamp is not applied to the assembly, and the assembly order (or operation inspection list) is noted "accepted on shortage record."

The assembly shortage record is prepared in duplicate for each assembly or small group of incomplete assemblies. This lists assembly part number, next assembly, missing parts, quantity of assemblies involved, and other pertinent data. One copy of the record is forwarded to inspection office for follow-up, and the other to the inspector in the area to which the short assemblies will be forwarded. It is the responsibility of this inspector either to make certain that the shortage is corrected or to forward the next-assembly item on its course with another shortage record attached.

If the shortage is corrected, the inspector's copy of the shortage record is stamped off and noted to that effect, then forwarded to the inspection office for matching up with the file copy. If it should be impossible to correct the shortage during the next assembly operations, and if it is necessary to forward the shortage to still another department, another shortage record should be originated, as the prime assembly number affected has now changed. The original shortage record is noted, with the assembly number of the new record, and is forwarded to inspection office files.

When more than one assembly is recorded on a shortage record,

the nature of deficiency must be *identical* on all listed assemblies. Should several assemblies have similar but not identical shortages, a separate record should be issued for each. Unless this practice is followed, the matching of short assemblies with

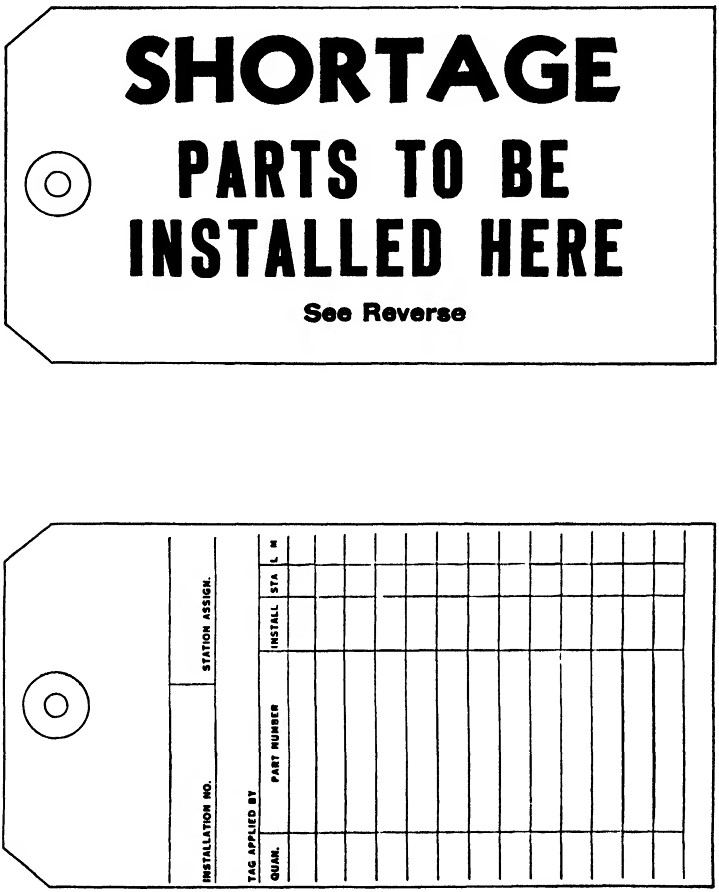


FIG. 2:9. Assembly shortage tag.

their proper shortage records may become difficult, and inspection control may become ineffective.

It should be apparent that this practice of issuing shortage records to permit moving incomplete assemblies places additional burdens and responsibilities upon both Inspection and Production Control. For this reason it should be considered as an emer-

gency procedure, to be used only when failure to move the incomplete assemblies will result in a serious production shutdown. Should this practice get out of hand through indiscriminate usage, a condition may soon be reached where all production stations are jammed with incomplete assemblies, and it is impossible actually to complete a single end item.

REWORK AND REJECTION

Frequent mention has been made of *rework* and *rejection* of items by Inspection. It is proper at this juncture to define these terms positively and to establish basic criteria for determining the required action in cases of improperly manufactured items.

Items are returned for rework when the error is such that it can be corrected by proper application of normal manufacturing processes. For instance, a turned shaft found to be oversize can be returned to the responsible department for rework. Should the shaft be undersize, normal rework is obviously impossible, and the part must be *rejected* for salvage disposition. Before rejecting an item, inspectors should be positive that the item deviates from specifications in a manner that will not permit correction through normal rework methods.

To be acceptable after rework, the item must (1) perform its intended function; (2) interchange with an identical item manufactured without reworking; (3) conform to dimensions, material, processes, and other pertinent specifications applying to the item; and (4) meet all strength requirements.

Whenever possible, the rejection notice should be attached to the defective item or items with a tag wire, to minimize the possibility of accidental removal. Items too small for individual attachment should be placed in a container, with the rejection notice attached.

It is not necessary to locate the rejection notice immediately adjacent to the deficiency. However, the inspector should describe, upon the face of the notice, the exact location and nature of the defect.

A rejection notice should not be removed by other than Inspection personnel. Nor should an inspector normally remove the notice unless the item has been approved, repaired, or re-

worked to the inspector's satisfaction in accordance with salvage committee instructions. Only the salvage committee normally is empowered to override a rejection without repair or rework (see Chap. 13).

Sometimes a rejection notice is detached from the rejected item and lost. This can result in confusion in completing salvage action on the item. Such losses also affect the company's quality standards and, in the case of government contract items, may jeopardize the company's "approved" quality rating. It should therefore be the responsibility of all Inspection personnel to make certain that rejection notices are properly attached and to resecure all that are found poorly attached. All unattached rejection notices found in the shop should be immediately forwarded to the chief inspector's office and an intensive search be made to locate the item or items affected.

Unauthorized removal of rejection notices is a serious matter, and severe penalties should be imposed upon personnel responsible for such acts. Because of the possibility of jeopardizing the company's reputation through unauthorized removal of rejection notices, this offense should be regarded as cause for dismissal.

The only exception regarding removal of rejection notices by other than the salvage committee is in case removal is necessary to preserve the notices during rework operations. In such cases the inspector in the area where the rework is to be accomplished should remove and retain the notice until the rework has been accomplished. Then the notice should be immediately reattached.

CHANGE CONTROL

Changes in dimensions, processing, and assembly requirements often become necessary during manufacture of a product. While these are undesirable, they are nonetheless unavoidable, as the result of engineering errors, changes in production methods, and changing customer requirements. Inspection's responsibility with changes is to insure that all items are manufactured in accordance with the proper change versions of relevant drawings and specifications, as listed on sales orders, shop orders, assembly orders, and advance drawing change documents.

Drawing changes issued through normal, routine channels rarely cause difficulty. Normal procedure identifies each change version of a drawing by a letter or a number, and this is shown on the shop or assembly order. The inspector simply makes certain that the items are manufactured in accordance with the proper change-version drawings.

In the case of advance drawing change (ADC) documents, issued to provide immediate information on changes to be accomplished in production as soon as possible, a genuine problem may exist. These ADC's are usually issued through an expedited system and reach the factory departments in advance of drawings incorporating the change information.

A copy of each ADC is normally attached to every print of the affected drawing. However, these may become accidentally detached from prints, and there is no assurance that all active ADC's are attached to prints used by inspectors for checking purposes.

It is highly desirable that the Inspection office establish a control over all ADC's (and other change information), with one person in charge of this activity. It should be the responsibility of this change-control function to maintain complete reference files of all change data, arranged both by part number and by change-document serial number. Copies of all relevant change data should also be supplied to each inspection station for use in actual inspection operations.

When precise control of change incorporation is considered necessary, a suitable *change checkoff list* should be prepared by Change Control for each assembly, listing all change documents affecting the assembly. This should be forwarded to the inspector in charge of the station where the assembly will be inspected. The inspector is responsible for checking the assembly in accordance with all change data shown on the checkoff list and for placing an accepted stamp opposite each item as the changes are incorporated. When the assembly is forwarded to the next department, the inspectors should list all unincorporated change data on a shortage record and should forward the shortage information with the assembly. The checkoff list for the assembly, showing both incorporated and nonincorporated change data is

forwarded to Inspection Change Control. The change checkoff listing should be a part of the *inspection operation list* when that document is used.

Inspectors in fabricating departments require a much less complicated procedure to insure that all relevant change data are incorporated in detail items. In these cases it is necessary for the inspector to check only with the Inspection station change-data file, to obtain all active changes relating to the item, and to verify the completeness of ADC's attached to the drawing print that accompanies the shop order. The items should not be accepted until all relevant change data have been incorporated. It is also advisable for the inspector to note in ink on the back of the Production Control copy of the shop order the serial numbers of all ADC's incorporated in the particular lot of items, followed by an acceptance stamp. This provides Production Control with a positive record of the status of each lot.

Under no circumstances should Inspection accept as authentic changes marked with pencil or ink on drawing prints. In some smaller plants there is often a tendency for engineering personnel to mark prints in an effort to correct rapidly errors that have been discovered during manufacture. This practice has nothing to recommend it, as the change action is not properly recorded. Loss of the single marked-up print may place Inspection in the position of having accepted items subsequently found to be incorrect, without record of the authorization for acceptance. When such practices exist, Inspection should prevail upon top management to inaugurate a formal procedure for issuance of advance engineering information.[4]

INSPECTION STAMPS

Acceptance and rejection stamps are assigned to each inspector for identifying the disposition of all items inspected. Salvage acceptance and scrap stamps are usually issued only to members of the salvage committee. The usual practice is to issue each stamp in pairs, one of steel and the other of rubber. These

[4] See Thompson, James E., "Engineering Organization and Methods," Chap. 11, McGraw-Hill Book Company, Inc., New York, 1947.

stamps are considered part of an inspector's tool equipment and should be in his possession at all times during working hours. Each inspector is responsible for the safekeeping of all stamps assigned. The stamps must be kept in good condition at all times and be surrendered to the Inspection office upon termination of employment.

Each stamp should bear a serial number, to identify the inspector to whom it is issued. Stamps should never be used by other than an inspector and under no circumstances should be loaned, even to another inspector. Unless this practice is rigidly adhered to, it becomes impossible to fix responsibility for improper inspection work. The usual penalty for unauthorized use of inspection stamps is immediate termination of employment.

Application of Stamps

Application of an acceptance stamp to an item and/or its accompanying order signifies that Inspection has determined the item to be in accordance with applicable drawings and/or specifications or that it is acceptable under an existing engineering deviation, standard repair, or salvage committee's disposition. Applying a stamp opposite an inspection entry on an order signifies that the listed operations are in accordance with applicable drawings and/or specifications. In all cases the stamp should be applied in a legible manner.

Steel stamps should *not* be applied to (1) bearing surfaces, (2) ferrous sheet thinner than 0.025 in., (3) nonferrous sheet thinner than 0.032 in., (4) highly stressed areas or items, (5) material harder than Rockwell 43–C (428 Brinnell), and (6) any item that might be damaged by stamping. In case the use of a steel stamp is not practicable, a rubber stamp should be used. Small, numerous, or delicate items need not be stamped in any manner, but should be identified by being placed in a closed container with a properly stamped tag attached.

Stamps should normally be applied adjacent to the part number appearing on an item. However, in all cases the stamp must be placed in a location that will not be obliterated or hidden by subsequent operations.

Types of Stamps

Endless varieties of shapes and sizes of stamps are used by different companies, but in each case their purposes are similar. The following examples of inspection-stamp impressions and their usage are typical of the variety required by a factory engaged in precision manufacture.

Detail acceptance stamps are issued both in steel and in rubber and comprise a circle enclosing the letter "A" and a number identifying the individual inspector, similar to the example below.

Detail acceptance stamp.

This stamp is used to record acceptance of individual operations on shop and assembly orders and to stamp completed detail items that are acceptable to Inspection. A similar, but smaller, stamp is often used during fabrication inspection to certify acceptance of a particular operation.

An *assembly acceptance stamp* is used to stamp accepted assemblies. This stamp is normally issued only in rubber. Its usage is necessary for positively separating assembly acceptance from markings previously applied in accepting details. All assemblies comprise one or more detail items that have been accepted in a fabrication department and that bear the detail acceptance stamp. The assembly acceptance stamp is similar to the detail stamp, but shows the abbreviation "ASSEM" below the stamp number, thus:

Assembly acceptance stamp.

Parts that meet heat-treat specifications are normally stamped with the *heat-treat acceptance stamp*. A small "H" enclosed

within a circle may be used to show acceptance of heat-treated parts having a limited area available for stamping.

Heat-treat acceptance stamp.

Alternative for small parts.

Items that require magnetic inspection are marked with the *magnetic inspection acceptance stamp.* In some cases a steel stamp is used. Where the use of a steel stamp might cause damage, a rubber stamp and etching ink can be employed. Items requiring 100 per cent magnetic inspection that are too small for any type of stamping can be identified after acceptance by being colored with a green dye. Items inspected by the sampling method, when less than the entire lot are given magnetic inspection, can be identified with an orange dye.

Magnetic inspection acceptance stamp.

In some cases a special stamp is used to show acceptance of welding operations.

Welding inspection acceptance stamp.

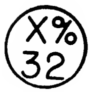
When highly critical pressure testing is involved on certain assemblies, it is desirable to record positively the accomplishment of the proper testing. A special *pressure-test inspection acceptance stamp* can be used.

Pressure-test inspection acceptance stamp.

Other special Inspection acceptance stamps that may be required are *X-ray* and *fluorescent-penetrant inspection acceptance* stamps. Two types of X-ray acceptance stamps are desirable.

One is for use when all parts in the lot have received X-ray inspection, and the other when only a specified percentage is subjected to this testing.

X-ray inspection acceptance stamp (100 per cent).



X-ray inspection acceptance stamp (less than 100 per cent inspection).

Fluorescent-penetrant inspection acceptance stamp.

Salvage Stamps

Three basic types of stamps are required to provide adequately for salvage action. The first is required to identify items *withheld* for salvage action through inspection rejection. Final disposition on all rejected material is determined by the salvage committee, to provide centralized control and responsibility for salvage and scrap actions. On this basis floor and booth inspectors do not make permanent rejections of items considered unacceptable but rather withhold these items from the production flow until they are reviewed by the salvage committee.

Thus, the "rejection" stamp used by inspectors is termed a *salvage withholding stamp.* A commonly used form comprises a letter "D" containing an identifying number. This is applied to unacceptable parts at the time rejection is made. No items bearing the withholding stamp can be used for production unless they also bear, in close proximity, the salvage acceptance stamp, signifying the salvage committee's approval of their use. The withholding stamp is *not* used for routine rework action. In these cases the items are returned to the department at fault, accompanied by a rework tag specifying the defect to be corrected.

Salvage withholding stamp.

Items reviewed by the salvage committee and found acceptable (either in their original form or after satisfactory special rework operations have been performed) are marked with the *salvage acceptance stamp.* This stamp is often a triangle containing a serial number.

Salvage acceptance stamp.

When the salvage committee authorizes the scrapping of items submitted for review, the salvage rejection stamp is applied. Company manufactured items rejected as scrap should, in addition to receiving the rejection stamp, be damaged sufficiently to prevent accidental usage.

Rejected parts that are to be returned to vendors should be neither damaged nor steel-stamped. Instead, a rubber rejection stamp should be applied.

Small items that will not permit application of the rejection stamp should be placed in a sealed container bearing a tag marked with the salvage rejection stamp.

Salvage rejection stamp.

Rejected tooling should be marked with a *scrap stamp.* This is not ordinarily applied to production items but is useful to tooling inspectors.

Tooling scrap stamp.

Company Identification on Stamps

The typical inspection stamps shown herein provide for identification of the using inspector, but do not identify the company. Such identification is often desirable, and on some items manufactured on government contracts it is mandatory. In such cases the stamps would be modified to show, in addition to the other markings, a symbol or letter code identifying the company.

COMPLETENESS OF END ITEMS

One vexing problem encountered by Inspection is the control of inspection activities to insure that each end item can be positively certified as being complete in every detail, manufactured in exact accordance with relevant engineering drawings and specifications, and functioning correctly when ready for shipment to the customer. The degree to which these facts can be positively certified is an excellent criterion of the soundness of Inspection's organization and methods.

The most important single item affecting Inspection's ability to guarantee completeness and accuracy of each end item is the character of production planning (shop orders, assembly orders, assembly-station lists, operation inspection lists, etc.) provided as indexes of operations and items required to produce the end item.

With accurate planning, the problem becomes one of selecting competent, conscientious Inspection personnel who will first verify that all items are fabricated in accordance with relevant shop orders. Each inspector involved in the subsequent flow through bench assembly, primary assembly, and final assembly is responsible for ascertaining that all items in his section of the factory bear stamps showing that preceding operations were acceptable and that the work coming under his scrutiny has the proper items, assembled in the correct manner.

With progressive verification that proper items are used and correctly assembled there should be little difficulty in producing an end item that meets all requirements. Failure of Inspection to detect and reject defective work is usually attributable to incompetent inspectors, improper supervision, or incomplete information. In other words, "Inspection was either careless or didn't know," when improper work has received an acceptance stamp. Neither reason is defensible.

When the production planning is incomplete or erroneous, Inspection should bring this condition to the attention of top management and should insist upon corrective action. In no case is it wise to build up a parallel system of records in the nature of an Inspection parts list of items required to construct an end item, except as a very temporary expedient. When such action

is taken, Inspection assumes a portion of the normal functions and responsibility of Manufacturing Planning.

Creation of an Inspection parts list results in two different (and often conflicting) records of the actions required to complete an end item. Shop personnel will be working to one record, while Inspection is checking to another. Confusion, misunderstanding, and ill feeling are certain to occur unless both shop and Inspection work to identical records, one making items in agreement therewith, and the other "buying" the completed work in accordance with the same record.

It must be admitted that in the case of a very poorly operated manufacturing planning organization it may be necessary for Inspection, as a protective measure, to establish independent records of the requirements of a completed end item, developed from applicable drawings and specifications. However, this should be considered only as a temporary expedient, and the principal effort should be placed upon convincing top management of the necessity of Manufacturing Planning's producing orders that are usable for both manufacturing and inspection purposes. As soon as this is done, preparation and use of the Inspection parts list should be discontinued.

CHAPTER 3

ORGANIZATION

There are two prime considerations involved in the organization of an inspection department: (1) Inspection's place in the general organization structure, and (2) the proper internal organization for the department. Each consideration can best be resolved by examining the basic functions to be executed by Inspection. Examination of the functional structure of any activity always permits logical assignment of responsibility and authority to create a sound, workable organization.

INSPECTION'S PLACE IN THE COMPANY ORGANIZATION

Inspection's basic function is maintaining product quality at the level established by top management. On this basis it appears logical that Inspection should report directly to top management and be on the same organization level as the engineering, manufacturing planning, and production functions. In a majority of cases this condition prevails. There are some instances, however, in which an ill-advised management has placed Inspection in the position of being responsible to the production function. This arrangement rarely operates in a satisfactory manner. It is difficult to find a production manager who can satisfy the requirements of meeting manufacturing schedules and of impartially approving rejection of defective items.

The undesirability of placing Inspection in a position of being subservient to the executive responsible for production was demonstrated by product-quality difficulties experienced in production plants in which this condition existed during World War II. Official case studies of war-production plants prepared

by the military establishment contain several examples, of which the following is typical.[1]

The function of inspection was moved about in the management structure. Government personnel familiar with the operations of this company have expressed the opinion that this function could have been handled more expeditiously had it been placed under the direct administration of the general manager.

The inspection department was largely subservient to the production department. Since the cessation of hostilities the inspection department has been relieved of its responsibility to Production, and has been made directly responsible to the general manager. This prevents the production department from dominating Inspection, and permits the inspection department to maintain its standards without undue pressure from production personnel.

In general, it is conceded that Inspection should be on the same level as other basic departments involved in the general organization of a manufacturing concern. The only logical exceptions are found in certain organizations producing extremely precise products. In these instances there appears to be some logic in establishing Inspection as a subdivision of the engineering department.

INSPECTION AS A DIVISION OF ENGINEERING

In the case of an engineering department engaged in the design of small devices involving considerable machining to close tolerances, fine coordination is needed between design and inspection. This is often done by establishing Inspection as an engineering function.

This arrangement is quite satisfactory when the total Inspection and Engineering personnel are few in number, but it places considerable burden upon the chief engineer in the case of a large operation. When the inspection program is extensive, involving considerable personnel, the inspection activity may be nearly as large as the engineering department. Good organization, then,

[1] From "Construction and Production Analysis" of World War II Aircraft Production, prepared by the Air Technical Services Command, edited so as to eliminate identification of the company involved.

demands that it be a separate department, responsible to top management and directed by a chief inspector. Coordination of Inspection with Engineering can then be accomplished by salvage engineers assigned as members of the salvage committee.

These salvage engineers assist in the application of quality standards established by drawings and specifications and provide decisions on questionable items. All incorrectly manufactured items accepted through salvage action must be approved by the salvage engineers.

ESTABLISHING THE FUNCTIONAL PATTERN

The first step in determining a logical Inspection organization is establishing the proper functional pattern. To be sound, this pattern should be applicable to the inspection department of any manufacturing enterprise engaged in manufacturing end items, regardless of the product that is being manufactured. It is necessary to distinguish between firms engaged in end-item manufacture and those occupied in materials processing, as their basic inspection functions are not entirely the same. This can be demonstrated by comparing the inspection activities of a firm engaged in the manufacture of cement with those of a producer of farm machinery. Both would require quality control activities; but the former would primarily require chemical analysis of the raw materials and physical tests of the product, while the latter would require not only these functions but also a variety of intermediate examination during fabrication and assembly operations.

The inspection functional pattern is sufficiently different in each case to justify separate treatment, and this discussion will be devoted exclusively to organization and methods applicable to the inspection department of concerns engaged in end-item manufacture.

It is immaterial whether the end item be an airplane, a harvester, or a refrigerator. The basic functional pattern will be substantially the same. Similar problems will be encountered, although the quality standards may vary, and the detail organization and methods required for solving the problem efficiently will be parallel.

INSPECTION-DEPARTMENT FUNCTIONS

The obvious function of Inspection is maintenance of established quality standards for a given end item or end items. The execution of this function requires a variety of supporting activities to develop the inspection plan, prepare necessary instruc-

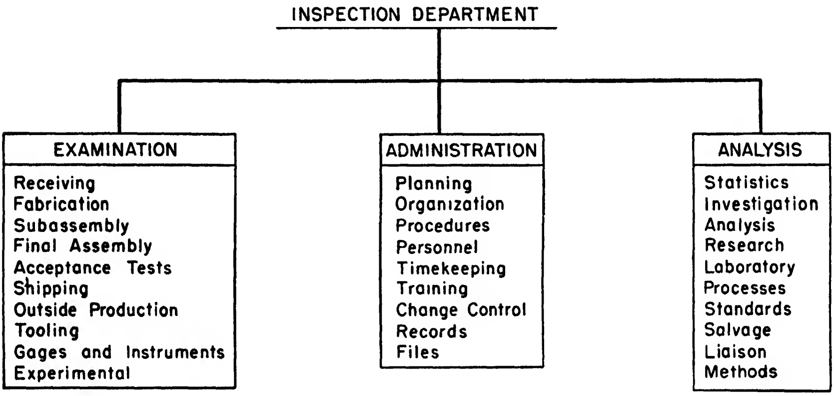


FIG. 3:1. Inspection-department functions.

tions and procedures, develop liaison and coordination with other departments, provide administrative and analysis services, and maintain necessary clerical functions and records.

Analysis of basic Inspection activities readily reveals that the prime functions are (1) examination, (2) administration, and (3) analysis. All inspection activities can be grouped under these three headings, and the functional breakdown in Fig. 3:1 lists the work normally relating to each.

EXAMINATION

Examination as a basic function of Inspection involves physical checking and testing of parts, assemblies, end items, manufacturing processes, and equipment, to ascertain that required quality standards are maintained. It is highly desirable that a uniform quality standard be maintained for all products manufactured by the company. Unless this is done, both Manufacturing and Inspection personnel will be confused by the necessity

of working under a variety of conditions, depending upon the particular item that is being manufactured. Errors in manufacture and inspection are certain to be multiplied in almost direct ratio to the variety of quality standards.

H. P. Dutton, associate editor of *Factory,* quotes the following example [2] of the problems involved with multiple quality standards:

> A manufacturer of fine laboratory furniture . . . thought once to keep his force busy during a dull season in the sale of equipment to college and research laboratories, by turning his factory to the making of manual training desks, a product in which the tolerances and finish are customarily of a lower order. The manufacturer had all the necessary equipment, and his men were skilled craftsmen who could easily turn their hand to the production of virtually anything made of wood. Markets in both cases were schools.
>
> On paper the plan was logical, but he found that if he put his men on the new product he must reconcile himself to one of two incompatible alternatives. Either he must produce manual training desks of a quality higher than was needed or would be paid for, or he must disorganize the habits of careful workmanship which had won a name for his major product. The manufacturer discontinued the new product. It would have been necessary to build up an almost completely new organization to have carried on the two lines with both commercial and technical success.

As a general rule, the best results are obtained when the entire company is operating on a single quality standard. In cases in which the economics of manufacturing makes necessary the production of items that vary in quality standards, it is desirable that products conforming to each level of quality be produced in separate operating divisions.

An application of this principle can be seen in the case of General Motors Corporation, which produces automobiles in every class of the quality range, but each in a separate, autonomous operating division. The problems of attempting to produce both Chevrolet and Cadillac motorcars in the same division are obvious.

[2] "Production Planning" (Plant Operation Library No. 100), Factory Management and Maintenance, 1946, pp. S–93 and S–94.

Administration

The general business activity, or *administration,* of the inspection department is one of the most important functions involved in its successful operation. The best operating plan, based upon perfect methods, will fail unless properly administered.

In a small department the full administrative responsibility rests upon the chief inspector, but in larger departments this is often delegated to an *administrative inspector,* who relieves the chief of a majority of details involved in administering inspection activities. The most important considerations involved in inspection administration are a sound operating plan, proper organization, satisfactory personnel relations, sound procedures, complete records, and adequate change control.

Analysis

This function involves investigation of inspection results to locate points in the manufacturing process where quality is deteriorating. Causes of defects are determined, responsibility is established, and recommendations for changes to prevent their recurrence are prepared. Findings of this function of Inspection are used to develop changes in the operating plan, as analysis indicates excessive or deficient inspection at certain stations in the production flow. Liaison with other departments is a normal activity of the analysis section of Inspection.

Data compiled by the analysis section can be of assistance also in determining the practicability of manufacturing the product within the quality standards established by Engineering. It may be found that the limits established by engineering specifications are such that the product cannot be economically manufactured with available production equipment; or that these limits are unreasonably narrow, in view of assembly requirements, or of the end use of the product. In such instances the analysis section can perform a valuable service to the company by pointing out these narrow limits and requesting suitable changes in engineering specifications. Obviously, changes should not be requested that will jeopardize performance or strength of the product.

The analysis function of inspection also carries the responsi-

bility of *statistical-quality control.* Properly applied, statistics are an invaluable aid whenever inspection can be conducted on a sampling basis (*i.e.*, less than 100 per cent inspection). In the absence of mathematically exact statistical methods based upon practical application of the *law of probability,* sampling inspection becomes a cut-and-try method and is inherently perilous to the integrity of the product. When proper statistical methods are employed, the highest possible accuracy of inspection and minimum chance of defective items reaching the customer are assured. Statistical methods as an alternative to 100 per cent inspection are not, however, recommended in cases in which failure may endanger life or property.

The methods involved in statistical-quality control are complex, involving mathematical operations of a high degree, and presentation of them in detail is beyond the scope of this discussion. Therefore, the reader is referred to some of the excellent publications dealing exclusively with this subject.[3]

BASIC INSPECTION ORGANIZATION

The departmental functions shown in Fig. 3:1 can readily be converted into a basic inspection-organization chart. This is shown in Fig. 3:2, where a small inspection department is organized on the basis of three general supervisors[4] reporting to the chief inspector. The number of supervisors reporting to the chief inspector should be kept to the absolute minimum in all cases, to avoid his becoming so enmeshed in details that he is unable to devote sufficient time to major issues.

The basic objective of organizing any activity revolves around the establishment of a staff of general supervisors who carry out the operations and are directly responsible to the management.

[3] Grant, E. L., "Statistical Quality Control," McGraw-Hill Book Company, Inc., New York, 1946; American War Standards Z1.1 and Z1.2, "Guide for Quality Control and Control Chart Method of Analyzing Data," American Standards Association, New York, 1941; American War Standards Z1.3, "Control Chart Method of Controlling Quality During Production," American Standards Association, New York, 1942; Shewart, W. A., "Economic Control of Quality of Manufactured Product," D. Van Nostrand Company, Inc., New York, 1931.

[4] The job title, "general supervisor," as used herein, refers to all personnel reporting directly to the department head.

Inspection Management is represented by the chief inspector, and as long as the department is very small, it is possible for the chief inspector to direct personally the operations of all functions; but when the department increases in size, this no longer remains feasible, the growth resulting in too much responsibility for one person, too many details, too many decisions. The chief

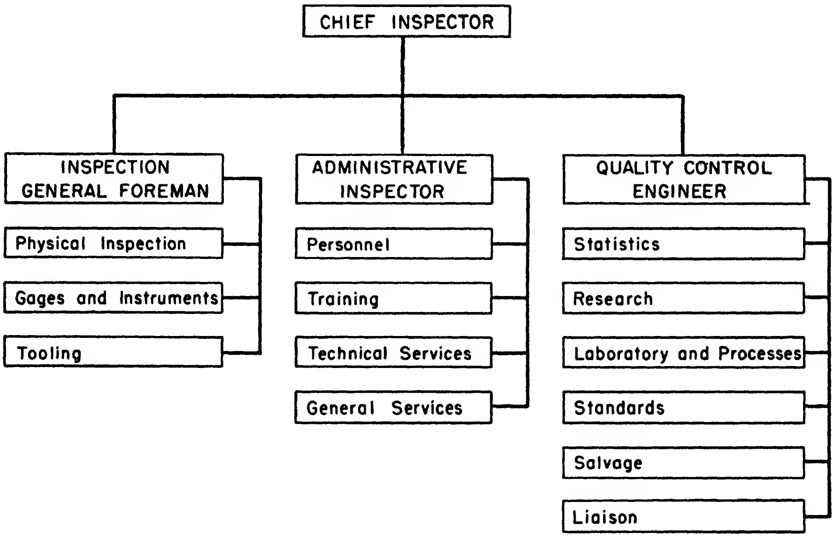


FIG. 3:2. Functional plan for small inspection department.

inspector who insists upon carrying the entire load will soon find it increasingly difficult to concentrate on the matters at hand, difficult to make even simple decisions. The chief will become uncertain of himself and correspondingly irritable. This mood will infect those in contact with the chief inspector and will spread throughout the department, resulting in a general deterioration of morale.

LINE ORGANIZATION

The solution, which is not difficult, involves simply the application of the military principle of line organization with a staff command. Instead of the department's operating as a one-man organization, it then functions as a group of coordinated functional subdivisions, each managed by a general supervisor, who

acts with the chief inspector's authority on certain delegated functions.

These general supervisors are selected and retained for their ability to apply the chief inspector's policies to each situation and to arrive at substantially the same decision that the chief himself might have made. The chief inspector is then free to devote undivided attention to developing and perfecting policy and to dealing thoroughly with new problems that have been referred to him for solution by the general supervisors. The same general policy should be followed with detail supervisors responsible to the general supervisors.

Application of the principle of staff command to an inspection organization not only is important from the viewpoint of the chief inspector but is also vitally important to the company as a whole. For with this type of organization, the company may feel secure in the knowledge that, should the department head become incapacitated, the general supervisors would be qualified to carry on until a suitable replacement for the department head could be found.

After a staff has been established to operate an inspection department, it is desirable to inaugurate the practice of regular, scheduled meetings of the chief inspector and his staff. At these meetings progress reports can be reviewed, budgetary matters can be discussed, policy corrected, and special problems studied and solved. This avoids the reevolution of a dictatorial organization, in which orders and decisions are arbitrarily handed down by the chief inspector; and it insures the workability of a staff-command organization. A similar practice should prevail of regular meetings of each general supervisor with his detail supervisors, to precede the staff meetings. This should not be interpreted as a recommendation for "committee management," but rather for staff reviews of progress and problems.

GENERAL STAFF FOR A SMALL INSPECTION DEPARTMENT

The three general supervisors shown in the chart in Fig. 3:2 are an adequate general staff for a small inspection department. To each is delegated the authority to accomplish certain basic

functions necessary for the successful operation of the department.

Maintenance of product quality through physical inspection of materials, parts, assemblies, and tools becomes the responsibility of an inspection *general foreman*, who is provided with inspection foremen to supervise each major subdivision of physical-inspection activities. An *administrative inspector* directs all inspection services (including procedural standards) and personnel matters. Research, statistics, working standards, salvage, and liaison are the responsibility of a *quality-control engineer*. The inspection general foreman, the administrative inspector, and the quality-control engineer form a basic staff for the inspection department.

The job titles shown for the three general supervisors established in the chart in Fig. 3:2 have been selected as most descriptive of the responsibilities of each. They are based upon study of actual inspection organization of a variety of firms engaged in the manufacture of precision products. It should be understood that the basic functional subdivision of the organization into *examination, administrative,* and *analysis* is the important matter and that job titles are of minor significance. For instance, the functions delegated here to the administrative inspector could be carried out equally well by an "executive inspector" or an "inspection manager," *but in each case the basic functions will remain the same, regardless of the job title.*

FUNCTIONAL PLAN FOR A LARGE INSPECTION DEPARTMENT

A functional pattern suitable for a large inspection department is shown in Fig. 3:3. The inspection general foreman, the administrative inspector, and the quality-control engineer remain as the basic staff; but the function of physical inspection has been divided into the two activities of *manufacturing* and *tooling*, with a foreman responsible for each. This separation is desirable, to avoid excessive responsibilities for any one staff member, and provides logical grouping of related functions. Experimental inspection, requiring a high degree of precision, becomes a responsibility of the foreman in charge of tooling inspection.

The position of *chief clerk* is established. This relieves the administrative inspector of direct responsibility for strictly clerical functions. If the department is quite large, personnel matters may demand the full-time attention of a capable person. In such a case this should become a separate function, responsible to the administrative inspector.

Inspection change control is a responsibility of the chief clerk, being handled by a group responsible for analyzing all incoming

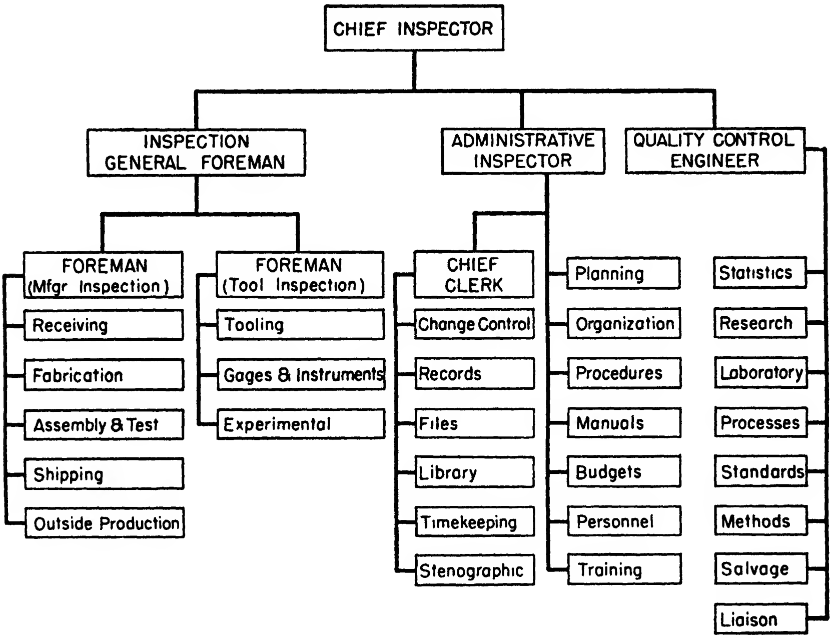


FIG. 3:3. Functional plan for a large inspection department.

change data, forwarding proper information on changes to all inspectors affected, and maintaining suitable records of change incorporation as part of the inspection logs. Incoming correspondence is routed to the chief clerk, who ascertains the effect of each and forwards copies to the persons affected. Follow-up is maintained to insure prompt and proper action on all correspondence. A detailed record is kept of contractual obligations, and those concerned are informed regarding their part in the fulfillment. The administrative inspector is kept aware of all progress and deficiencies.

ORGANIZATION OF DIVISION INSPECTION DEPARTMENTS

The value of a staff-command organization becomes increasingly apparent as the magnitude of inspection activities increases. The establishment of an inspection organization for a corporation having several operating divisions would be difficult unless it were handled in this manner.

The preceding outline of functional organization was based upon the requirements of Inspection in a self-contained company. When the company has two or more operating divisions, each with its own inspection department, the problem becomes more complex. A different functional organization is required, to provide corporate control over the inspection department of the operating divisions.

A basic inspection organization suitable for a corporation with several operating divisions is shown in Fig. 3:4. Each division

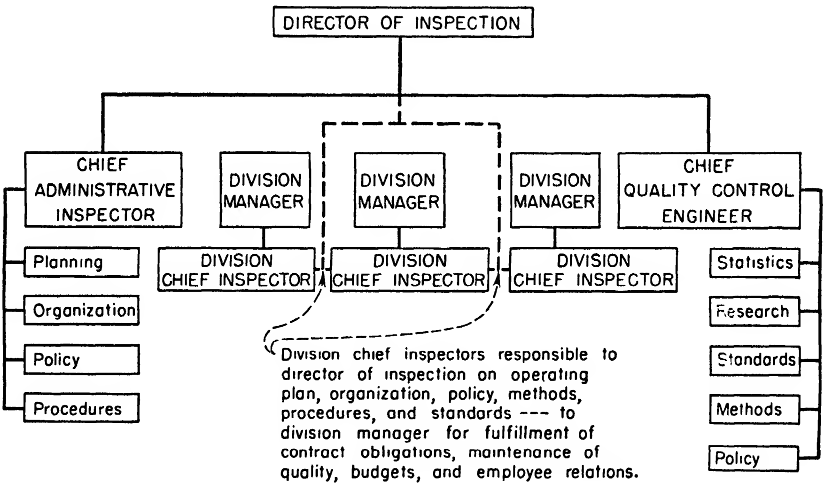


FIG. 3:4. Functional inspection organization for a corporation with several divisions.

inspection department is managed by a division chief inspector, provided with a basic staff that includes a general foreman, an administrative inspector, and a quality-control engineer.

The corporate inspection structure for all divisions is headed by a director of inspection, assisted by a chief administrative inspector and a chief quality-control engineer. To avoid each

division chief inspector's being continually frustrated by dual responsibility, it is necessary to define his duties both to the director of inspection and to the respective division managers in a way that prevents overlap and conflict.

Each division chief inspector is basically responsible to his division manager for all matters peculiar to division operation. On the other hand, the director of inspection, being responsible for the basic operation of all inspection activities, must maintain control over those matters which affect *all* division inspection departments.

The division chief inspector is responsible to the division manager for maintenance of quality standards established for the division's products, fulfillment of contractual obligations, adherence to budgets, and proper direction of inspection personnel; and to the director of inspection for organization, methods, procedures, adherence to the basic inspection plan and standards, and policy.

Functions affecting the operation of all divisions, irrespective of the products manufactured by each, are directed by corporate general supervisors, responsible to the director of inspection. Analysis, including establishment of basic inspection standards, is handled by the chief quality-control engineer. Division chief inspectors who require research or development have this work accomplished by the chief quality-control engineer.

The administrative functions affecting all divisions are directed by the chief administrative inspector. Important among these functions are methods and procedures planned to insure uniform practices in all division inspection activities, as is the necessary inspection planning to insure meeting division quality obligations.

DETAIL ORGANIZATION

In Figs. 3:5 and 3:6 will be found detailed organization plans suitable for both small and large inspection departments. They are based upon the functional organization shown in Figs: 3:2 and 3:3. An inspection organization suitable for a small manufacturing company is shown in Fig. 3:5. All physical inspection is the responsibility of a general foreman.

The plan shown in Fig. 3:5 is applicable to the operations of a company that has 500 to 1,000 employees and is engaged in the manufacture of a moderately precise product. In the case of smaller organizations, the organization can be contracted accordingly. Inspection in fabrication and assembly operations can be placed under a single foreman, responsible also for receiving and shipping inspection. The duties of the quality-con-

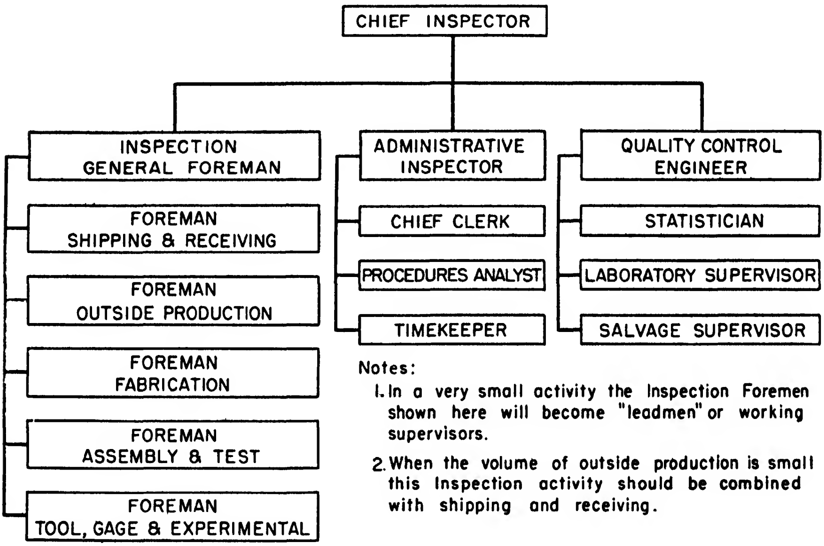


FIG. 3:5. Organization of small inspection department.

trol engineer can be assigned to the administrative inspector, with the result that only two general supervisors report to the chief inspector.

In the case of a very small operation, the inspection general foreman would become a "foreman," and his subordinates would be "assistant foremen," or even "leadmen," to reduce the quantity of supervision and increase the percentage of personnel occupied in accomplishing actual physical-inspection work.

ORGANIZATION OF AN EXTENSIVE INSPECTION DEPARTMENT

When the inspection department increases in size, it will be found that the simple organization shown in Fig. 3:5 is not en-

tirely adequate. It becomes necessary to subdivide certain functions further. This involves a rearrangement, rather than a change, in the basic functional pattern. A suitable arrangement for a large inspection department is shown in Fig. 3:6.

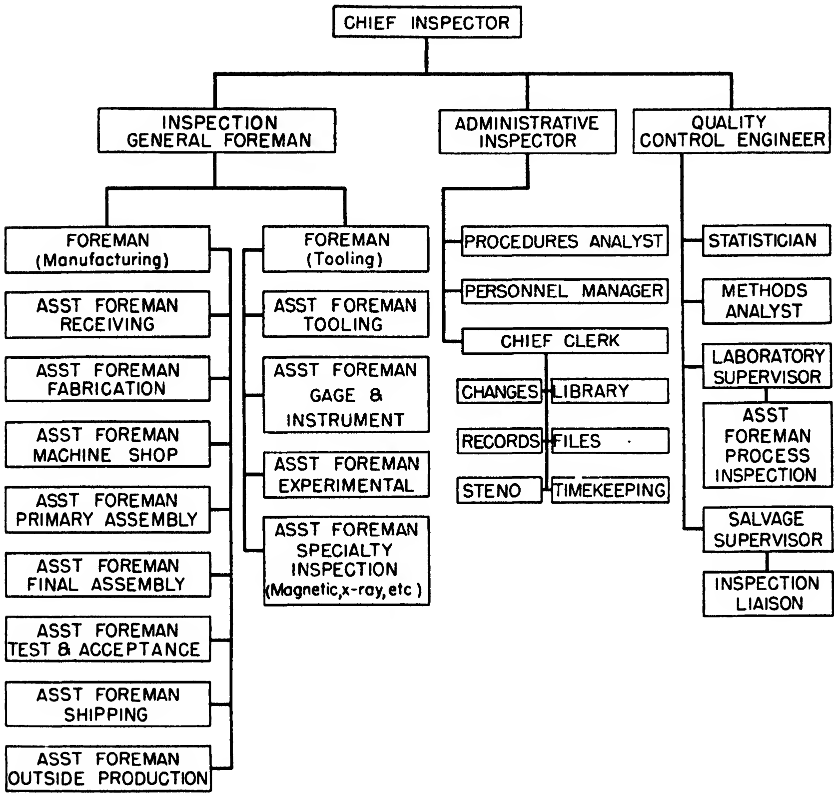


FIG. 3:6. Organization of extensive inspection department.

As the inspection task increases in magnitude and complexity, it becomes increasingly essential to maintain at a minimum the number of general supervisors who report directly to the chief inspector. Unless this is done, the chief inspector's time will be largely consumed by the reports and problems of a host of subordinates. The problem is solved in the organization shown in Fig. 3:6, in which one general supervisor is placed in charge of each of the three prime inspection functions: physical inspection, administration, and analysis.

An inspection general foreman directs all physical inspection through manufacturing and tooling inspection foremen. The quality-control engineer directs all phases of analysis and research. The administrative inspector is responsible for all operational phases of the inspection department and, in general, becomes the business manager of the department. This comparatively simple arrangement provides that the chief inspector shall receive reports from but three people.

In some instances the manufacturing operations of a large company may be located in two or more separate factory buildings, rather than under a single roof. Sometimes these buildings are separated by a distance of several miles, fabrication being accomplished in one plant and assembly at another. When this is the case, it is desirable to have a general foreman in charge of inspection at each plant. Thus two or more general foremen may be required, to carry out the functions of the one general foreman in charge of physical inspection shown in Fig. 3:6.

ORGANIZATION OF A MAINTENANCE INSPECTION DEPARTMENT

In the case of maintenance inspection activities, such as those required by an air line, the functional responsibilities are somewhat simplified. Inspection's primary concerns relate to *maintenance, overhaul,* and *receiving,* as shown in Fig. 3:7. This ar-

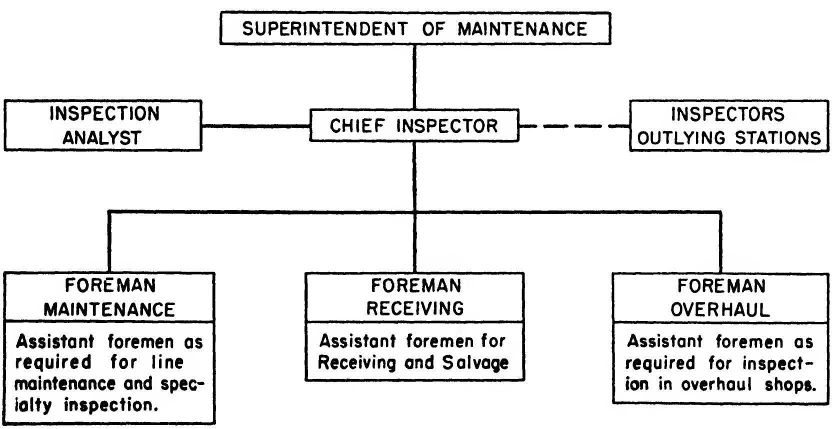


FIG. 3:7. Organization of maintenance-inspection department.

rangement provides a maintenance inspection foreman to supervise all routine, periodic inspection of operating equipment; an overhaul inspection foreman to control the quality of parts and equipment processed through the overhaul shops; and a receiving inspection foreman, who is responsible also for salvage action.

In the case of a transportation operation, certain maintenance work must be accomplished at outlying stations along the system. Inspectors at these stations are responsible to the chief inspector on matters relating to policy, methods, and standards. In all other matters these inspectors are responsible to their respective station manager, in order that each station manager may have complete administrative control over all personnel assigned to the station.

ASSISTANT CHIEF INSPECTOR

The organization arrangements shown in Figs. 3:1 through 3:7 do not provide for an assistant chief inspector or for assistants to the general supervisors. These can be established as they may be needed to relieve executives of excessive detail work. In the case of an assistant chief inspector, this position can be considered analogous to a "chief of staff" who conveys the chief inspector's instructions to the general supervisors forming the "staff command" and makes certain that each properly executes his portion of the program. This leaves the chief free to concentrate on policy matters, on problems referred to him by the general supervisors, and on maintaining harmonious relations with other departments of the company and with top management.

LINE AUTHORITY

After an inspection organization has been established, certain basic principles of management must be followed, to insure its proper operation. Again we may borrow a military expression to illustrate the point and say that it is necessary for all instructions, complaints, requests, and assignments to "go through channels." All must flow along the established lines of authority, and in no case should any member of the inspection department

pass over a superior or a subordinate when transmitting instructions, complaints, requests, or assignments.

Unless this policy is scrupulously observed on the part of all supervision and rigidly enforced on the part of employees, it is difficult to maintain morale and discipline within the department. The employee must *first* take all problems to his foreman and must in every case receive his instructions from the same person if he is to have proper respect for the foreman.

Employees should not receive from a general supervisor decisions on matters that are under the jurisdiction of foremen; instead, they should be referred back to their foreman. On the other hand, the general supervisor (or department head, for that matter) who issues instructions directly to the employees of a foreman (even though subordinate to the general supervisor) is guilty of a cardinal error. Such practices destroy the foreman's prestige, with resultant deterioration of departmental morale.

ORGANIZATION CHARTS

It may seem that issuance of an actual, physical organization chart of the inspection department is relatively unimportant. This is not true. In fact, one of the most important steps in establishing a smoothly functioning department is the issuance of an organization chart, followed by immediate revisions whenever personnel or functional changes become necessary. When this is done, there can be no misunderstanding regarding the authority and responsibilities of the various supervisors and foremen. The department morale is greatly strengthened by the public announcement of the status of each person in the department.

Concurrent with the issuance of an organization chart, there should be distributed a brief statement defining the authority and responsibility of each person shown thereon. This can be similar to the examples shown in Chap. 4 and will clarify the status of each person in the department beyond the possibility of misunderstanding. The importance of these simple steps must not be underestimated. Nothing is more deleterious to departmental morale than uncertainty regarding responsibility and authority.

In conclusion, the essence of inspection-department organization involves determination of the functions involved; allocation of these to a *small* staff of competent general supervisors, each of whom directs a group of supervisors or foremen; followed by a clear-cut organizational scheme based upon positively defined duties and authorities.

CHAPTER 4
PERSONNEL

Administration of the inspection department, as separate from the examination and analysis activities, can be divided into two prime phases: business relations and human relations. The latter involves intelligent selection, classification, supervision, and leadership of employees.

Human relations and the technique of handling people deserve constant study by every supervisor, foreman, and leadman; *for a leader can be only as successful as his subordinates permit.*

Certain basic policy and procedure must be established as the foundations of human relations between supervisor and worker. The more important of these are considered briefly in this chapter. Few of these are unique to the inspection department but should be understood by all supervisors and foremen. Detailed consideration of the complexities of human relations is beyond the scope of this text, and the reader is referred to some of the excellent publications available that deal exclusively with the subject.[1]

UNION RELATIONS

In some cases Inspection direct-labor personnel are members of a labor union, and it is necessary for supervision to be thoroughly familiar with union contract stipulations and grievance procedure. The merits of labor organizations and the complexities of maintaining harmonious employee relations in the

[1] Heyel, Carl, "Human Relations Manual for Executives," McGraw-Hill Book Company, Inc., New York, 1939; Schell, Erwin Haskell, "The Technique of Executive Control," 4th ed., McGraw-Hill Book Company, Inc., New York, 1934.

presence of a labor union are topics sufficiently important to justify texts of their own, and are adequately treated in other publications.[2]

There are, however, two cardinal considerations when a portion of the personnel are members of a labor union. First, it must always be remembered and thoroughly impressed on all concerned that each and every supervisor and each and every foreman (and their assistants) are a part of management. Therefore, the union may consider the company liable, in whole or in part, for their acts, commitments, and errors of commission and omission. Further, it is vitally important that every member of supervision be thoroughly familiar with all union contractual provisions, and act strictly in accordance therewith. Dubious cases should be referred to the company official responsible for union negotiations, without the slightest prior expression of opinion on the part of inspection supervision. Even "off-the-record" opinions are dangerous and may jeopardize equitable settlement through established channels.

The second prime consideration is proper handling of union grievances. These are any and all complaints originating with a union employee. In cases in which a union has been awarded "exclusive bargaining rights," it may be improper for a supervisor or a foreman to discuss complaints directly with an employee, and all grievances must be handled through the established channels, usually involving a "grievance committee." The merits of this system are debatable, as a majority of complaints can usually be satisfactorily settled between employee and supervisor, provided that the supervisor is familiar with management policy and union obligations, is given proper authority, and is diplomatic. On the other hand, a poorly trained or "bull-of-the-woods" type of foreman can create havoc with employee relations.

In all cases, grievances should be handled in a manner that meets all union contractual requirements, and all supervision must be aware of the proper procedure that is to be followed.

[2] For instance, see Bethel, Atwater, *et al.*, "Industrial Organization and Management," Chap. XXI, McGraw-Hill Book Company, Inc., New York, 1945.

BASIC DUTIES OF INSPECTION PERSONNEL

The duties of the various supervisors, foremen, and personnel groups involved in the operation of an inspection department are briefly defined in the paragraphs that follow. The definitions are generally applicable to any inspection department but may require occasional modification to suit individual conditions present in a particular company. Many of the job titles have been arbitrarily chosen, on the basis of their being most descriptive of the job functions. It should be understood that basic functional organization is the important matter and that the job title is of minor significance.

Director of Inspection:

Establishment of inspection policy. Final approval of inspection operating plans. Contact between company and customer on matters affecting inspection policy and contractual obligations.

Chief Inspector:

Direction of inspection activities. Consultant and final approval on operational problems referred from inspection general supervisors. Final approval on inspection methods, procedures, and standards. Settling differences of opinion between inspection personnel and other factory departments, or customer inspectors. Responsible to management for maintenance of established quality standards.

Assistant Chief Inspector:

Responsibility for detail operation of inspection department, leaving the chief inspector free to concentrate on major policy matters: relations with other departments, management, and customers.

General Foreman—Inspection:

Direction of physical inspection for all production and experimental manufacturing, including tool and gage inspection. Approval of new inspection methods and major changes in existing methods.

Foreman—Inspection:

Supervision of physical-inspection activities in a given inspection group, including inspection practices, standard procedures, and personnel control within his group. Responsibility for maintaining quality standards for work relating to group. Maintenance of required inspection records.

Administrative Inspector:

Direction of inspection office management, operational procedures, arrangements for business trips, and approval of expense accounts. Direction of technical and general service groups, personnel management, and employee training. Inspection planning, cost control, and budgets.

Quality-control Engineer:

Direction of inspection analysis and salvage activities for production and experimental manufacturing. Development of new inspection methods and changes in existing methods. Responsibility for statistical-quality-control activities.

Methods Analyst:

Development of new and improved inspection methods. Work simplification. Maintenance of inspection specifications.

Procedures Analyst:

Development of company standard-inspection procedures. Preparation of inspection manuals.

Personnel Manager—Inspection:

Wage and salary administration. Procurement of inspection employees. Interviews with prospective employees. Maintenance of employee histories. Terminations. Vacations and leaves of absence.

Chief Clerk—Inspection:

Direction of inspection files, library, timekeeping, and change-control activities. Procurement of inspection-department supplies. Direction of stenographic and clerical employees.

Salvage Supervisor:

Supervision of investigation, inspection, and disposition of rejected items.

Laboratory Supervisor:

Supervision of inspection laboratory, and direction of process control, physical and chemical testing of materials and items, and performance testing of precision purchased items. Research on special inspection problems.

Statistician:

Maintenance of inspection statistics, and development of statistical quality-control methods. Analysis of inspection statistics, to determine points requiring additional inspection or receiving excessive attention.

Many of the classifications listed herein could be broken down into several levels of subordinate positions. This will be done only in the case of physical-inspection personnel. To attempt breaking each supervisory classification into its senior and junior subordinates, with an indication of the various related technical and clerical functions, would require an extensive listing and serve no useful purpose.

DETAIL DUTIES OF PHYSICAL INSPECTION PERSONNEL

The bulk of inspection activities are carried on by personnel engaged in physical inspection work. These include foremen, assistant foremen, leadmen, and inspectors. Their work accounts for a majority of Inspection contacts with other departments, and the execution of their duties largely controls Inspection's reputation within the company.

Foreman

Each inspection foreman should be acquainted with the detail significance of all instructions issued by Inspection management. In turn, each foreman should instruct all personnel under his supervision regarding proper interpretation and application of these instructions.

Foremen are responsible for assigning work to subordinates and for providing advice, instructions, and guidance in proper

accomplishment of the assigned tasks. It is also the foreman's responsibility to make certain that these tasks are efficiently executed, in accordance with the inspection plan and established quality standards.

Inspection foremen should attempt to settle disputes between inspectors and personnel of other departments, or the customer. When a foreman cannot reach a satisfactory agreement, the problem should be referred to his general foreman. When the general foreman cannot reach a settlement, the problem should be referred to the chief inspector.

Foremen should be thoroughly familiar with company policy, particularly that relating to industrial relations. Many organizations require that all foremen and supervisors receive regular training in employee and union relations.

Assistant-foremen positions are often established to relieve the foreman of selected detail responsibilities. In the absence of the foreman, the assistant foreman assumes the foreman's duties.

Leadman

Subgroups within a major inspection group are often supervised by leadmen, who report to foremen or to assistant foremen. Their general duties, while they are similar to those of higher level supervision, are of lesser magnitude and require close attention to detail work within a narrow field.

Each leadman has the responsibility of instructing all personnel under his supervision in the correct understanding of all pertinent inspection instructions and of making certain that these instructions are followed. This task includes assigning each subordinate to his duties, as directed by the foremen; determining the ability of each to perform the assigned duties; and rendering advice, instruction, and guidance, as required.

Differences of opinion between inspectors and personnel of other departments, or customer representatives, should be settled by the leadman whenever possible. When a satisfactory agreement cannot be reached, the leadman should refer the problem to his foreman. In no case, however, should the leadman consult general supervisors or executives in other departments when attempting to settle differences, but should confine his contacts to

personnel whose level of authority in the organization is comparable to his own.

All job-performance reports affecting personnel under his supervision should originate with the leadman. In many cases it becomes the leadman's duty to review these reports with each employee, making certain that all personnel evaluations are fair and accurate, and guiding deficient employees to improve their job performance.

Leadmen train their personnel in proper inspection techniques and in correct application of equipment, methods, and procedures. Work and work areas are assigned to each inspector in a manner that minimizes crowding or inefficient concentration of personnel. Inspection activities are planned, organized, and supervised to insure completion of the required work within scheduled times. Effective liaison with inspection personnel on following shifts, in cases in which the factory operates on a multishift basis, is a responsibility of the leadman.

Inspectors

The normal duties and responsibilities of various classifications of inspectors will be found in Appendix I. The job classifications listed therein provide for a majority of the detailed inspection duties normally encountered in manufacturing operations.

SELECTION OF INSPECTION EMPLOYEES

Selection of proper personnel for the positions of chief inspector and the Inspection "general staff" governs the success or failure of the inspection department. These men should be selected, primarily, on the basis of their *administrative* ability and, secondarily, upon their ability physically to accomplish inspection work. This does not mean that the top personnel of Inspection need not possess thorough knowledge of inspection methods and equipment, production equipment, and company products and policy. This background is vitally important, but it will not insure satisfactory results unless the person possessing this knowledge has also the know-how of departmental administration and the ability to get along with people.

Often a shop foreman is promoted to an important position in

Inspection. This practice of filling Inspection vacancies through upgrading company employees is highly commendable, but it is not always satisfactory for supervisory positions. Frequently it is best to go outside the company to obtain competent, proved personnel for top Inspection positions. Too often the shop foreman promoted to an important Inspection position will be too concerned with details, to the detriment of the over-all organization and planning required for efficient, harmonious operation.

In the case of nonsupervisory inspection personnel, it is entirely practicable to select these from the ranks of more skilled production workers. As a matter of fact, this method of recruiting inspectors often works to excellent advantage, as the time required for indoctrination and familiarization is minimized, and only a short time need be spent in training the new inspector to accomplish his assignment. In time, the best of these inspectors may be upgraded to fill vacancies in supervisory positions.

Bethel, Atwater, *et al.* state: [3]

> In spite of the use of measuring instruments and control devices, infallibility of inspection almost invariably depends upon competent inspectors; hence the importance that is attached to their selection and training. An inspector should be conscientious, thorough, exacting about details, and not afraid of routine. Important too is his ability to carry out orders and instructions faithfully. Keen eyesight as well as the manual dexterity required to handle small gages and parts in inspection and to ascertain the correct feel are also important.
>
> The ability to cooperate and deal with the personnel of the manufacturing departments is an important attribute of inspection supervision and inspectors alike. Generally, inspectors deal with people fully as much if not more of the time than they deal with inanimate equipment and material. All too often manufacturing personnel gain the impression that the primary aim of inspection is to prevent production. A cooperative inspection organization can often do much to demonstrate the true function of inspection: that of preventing *defective* production.

This ability to cooperate with personnel of other departments is one of the most important prerequisites for a good inspector.

[3] "Industrial Organization and Management," Chap. XV, McGraw-Hill Book Company, Inc., New York, 1945.

The author has witnessed some very unfortunate examples of excellent shop personnel's being transferred to inspection positions. Undoubtedly these men were well-qualified mechanics, but unfortunately insisted that all items be made in accordance with *their* idea of proper workmanship, rather than content themselves with ascertaining that all accepted items were within limits established by drawings and specifications. Some of these men were amenable to reorientation and became good inspectors before harm resulted. Others continued to insist on their ideas of workmanship, causing friction and ill feeling between Inspection and the shop departments, with the eventual result that these hardheaded individuals were transferred to work in other departments.

EMPLOYMENT INTERVIEWS

Preliminary interview of all prospective Inspection employees is a proper function of the company personnel department or, in the case of a large inspection department, of the inspection personnel manager. This screening eliminates the obviously unfit and directs promising candidates to the proper supervisor or foreman for final interview.

Screening Prospective Employees

It is obvious that an interviewer in the personnel department cannot be entirely familiar with the detail requirements of all positions in the company. Many companies have attempted to overcome this deficiency through the use of employment *aptitude tests,* to insure the accuracy of preliminary or screening interviews. Although tests of this nature are valuable when used as a *tool* in the selection of personnel, they often fail when permitted to become the major criterion in selection. In the latter case there may be introduced the hazard of rejecting not only the obviously unfit but also the exceptionally capable prospect, with the result that a majority of prospects referred for final interviews fall into the mediocre group. This condition is not so common a failing in aptitude tests, but it is a failing of stereotyped "temperament" tests.

When aptitude tests are used, they should be prepared to suit

actual job requirements relating to company products, rather than be given in the form of generalized questionnaires of the type frequently offered for sale by industrial-relations consultants. Tests should be prepared for each job and should be similar to the following example, used by the Airplane Division of Fairchild Engine and Aircraft Corporation for screening candidates for the position of tooling inspector. Two hours are allowed for completion of this test.

Test for Tool Inspection—A

The following statements have several possible answers given. Choose the correct answer and place its number in the space provided:

1. For checking flatness of a broad surface and for scribing straight lines in layout work one could use a (1) dial indicator, (2) universal square, (3) straightedge .... [ ]
2. Balancing points are indicated on long straightedges (1) for ease in handling, (2) so that they may be used with minimum deflection, (3) so that storage hangers can be properly spaced .... [ ]
3. The magnitude of the scale on a vernier protractor is (1) 360°, (2) 180°, (3) 90° .... [ ]
4. A sine bar may be used to set up and check any desired angle with the use of (1) an angle computer, (2) a dial index head, (3) trigonometry .... [ ]
5. A simple form of comparison instrument is a (1) cylinder gage, (2) dial indicator, (3) magnifying glass .... [ ]
6. A precision tool that bridges the gap between the hand micrometer and costly measuring machines is a (1) sine-bar carriage, (2) master bar, (3) supermicrometer .... [ ]
7. In recesses inaccessible to the ordinary steel rule a (1) steel rule with a holder may be usefully applied, (2) inside micrometer would be used, (3) combination square may be used ...... [ ]
8. To check the amount of deviation from squareness in thousandths a (1) machinist square and feeler gage may be used, (2) plain protractor may be used, (3) vernier micrometer should be used [ ]
9. "Play" in a micrometer screw can be taken up by (1) a slotted nut, (2) the clamp ring, (3) installation of the next oversize screw [ ]
10. A vernier caliper can be adjusted for accuracy by (1) filing the movable jaw, (2) moving the vernier scale, (3) nonadjustable .... [ ]

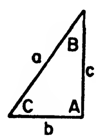
11. The sum of the angles of a triangle equals (1) a straight angle, (2) a right angle, (3) 360°, (4) 180° .... [ ]
12. A rapid method of inspection has been incorporated in a type of gage which checks the part with a standard and is known as (1) linear measurement, (2) amplification, (3) comparison measurement .... [ ]
13. The accuracy of a vernier caliper as a measuring instrument is to the nearest (1) ten-thousandth, (2) thousandth, (3) $\frac{1}{64}$ .. [ ]

If the following statements are correct, draw a circle around "Yes." If they are incorrect, draw a circle around "No."

14. The diameter of a drill may be obtained by measuring across the margins just behind the point .... YES NO
15. The most common inspection application made of the dial indicator is where it is used to indicate the variation in a dimension .... YES NO
16. Tolerance allowed on a part is the same as the tolerance on the tool ....YES NO
17. The hermaphrodite caliper is a cross between a divider and an inside caliper, having one leg of each. .... YES NO
18. A trammel is a tool used for the same purposes as a divider and caliper, but usually for distances beyond the range of either of these two instruments .... YES NO
19. A surface gage may be considered either as a nonprecision measuring instrument or as a precision instrument, depending on the measuring device used in connection with it .... YES NO
20. Telescope gages come in sizes from $\frac{1}{2}$ to 6 in. and are read in 64ths .... YES NO
21. The word "pin" in the language of tooling means a machined part with close tolerance .... YES NO
22. Tooling is provided to guarantee uniformity and interchangeability of parts or units and is indispensable to present aircraft manufacture. .... YES NO
23. The sides and surfaces of an angle plate are ground square or parallel with each other so that, when the angle plate is placed on the surface plate, it provides a perpendicular to the surface plate for clamping work .... YES NO
24. A plug gage would be used to check the depth of a hole to 0.005 in. .... YES NO
25. A surface gage would be used to check the amount of deviation when checking parallelism to a surface plate .... YES NO
26. Two times the radius of a circle equals the diameter .. YES NO

27. A difference of temperature caused by the fingers or breath on the level tubes of a transit has no effect on the bubble ...... YES NO
28. By taking horizontal sights at a scale held vertically, first at one point and then at another, the difference in altitude between the two points may be found with great accuracy .... YES NO
29. A plumb bob is a better leveling device than a transit .. YES NO

30. What two angular readings may be obtained by the use of a transit? ____________________
31. Ask for the micrometer and test block and record the four readings.
    a. ____________ *b.* ____________
    c. ____________ *d.* ____________
32. Ask for the vernier calipers and test piece and record the four readings.
    a. ____________ *b.* ____________
    c. ____________ *d.* ____________
33. Give the average of the five vernier height gage readings: 0.076, 0.097, 0.080, 0.079, 0.091 .... ____________
34. Add the following micrometer readings: 0.0642, 0.071, 1.03, 0.0076 .... ____________
35. Change 47/64 to a five-place decimal .... ____________
36. Change 0.8906 to its nearest fraction .... ____________
37. A 10″ sine bar is used to measure an angle. The heights from the surface plate to the measuring plugs are 5.605 and 3.026, respectively. What is the angle? .... ____________
38. In right triangle *ABC*, find angle *C*.
    Given angle *A*—90°
    side *b*—4.3″



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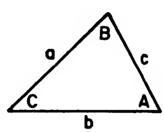
39. Find angle *C*.
    Given angle A—78°
    angle *B*—36°



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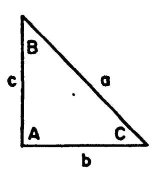
40. In right triangle *ABC*, find side *b*.
    Given side *a*—4
    side *c*—3



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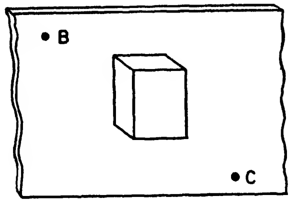
41. With the use of a transit, 3-ft. scale, and trig book, write the procedure for finding the distance, on a wall, from points *B* to *C* across an Electrical Junction Box.



42. Convert the following decimals to their nearest fractions:

0.02063	________	0.82713	________
0.077	________	0.963	________
0.6305	________		

QUESTIONS ON PRINT #78–320008 MCD 2 OF 10

43. What is the inside diameter of detail 204? .... ________
44. Give the length of detail 206 .... ________
45. Into what detail does detail 201 assemble? ...... ________
46. What two outside diameters are used on detail 206? .... ________
47. State the depth of the thread in detail 206 ...... ________
48. Of what is detail 202 made? .... ________
49. What would dimension $107\frac{15}{64}$ be on a full-scale print? .... ________
50. What construction is used on detail 210? .... ________
51. How far does detail 204 extend into detail 202? .. ________
52. What is the distance from the face of detail 205 to the center of the eyebolt holes? .... ________

Detailed aptitude tests for skilled jobs are invaluable in cases where a union contract requires that available jobs be posted for bid by company employees desiring to better their positions. In such cases only when the job cannot be filled through transfer or upgrading of an existing employee can it be made available to outsiders. When company employees bid for a job opening the selection is normally governed by seniority modified by experience. Use of a detail-aptitude test will largely eliminate personal judgment and prejudice in choosing among several employees who are bidding for a given job and who possess equivalent

seniority. Also, and even more important, it will make practicable the rejection of a bidder who possesses superior seniority but deficient experience, with minimum possibility of repercussion in the form of a union grievance.

Final Selection

The final decision on prospective employees recruited from outside the company should be made by the supervisor for whom the employee will work. The supervisor is responsible for accomplishment of certain specified duties, and it is only fair that he be permitted to select employees that he considers most suited for the achievement of the task.

Remuneration is an important consideration during final interviews of prospective employees. Each supervisor authorized to hire personnel must be familiar with company wage and salary schedules and should avoid starting new employees at or near the top rate for a particular job classification. Unless this caution is observed, it is difficult to reward good performance with wage increases except by reclassification, which is sometimes neither possible nor desirable. This situation may make necessary a starting rate lower than that previously earned by the prospective employee. The prospect will often accept the lower starting rate if the position is shown to offer good opportunity for advancement or considerable security.

Care must be used to avoid expressed or implied promises of future wage increases. Unless there can be definite assurance that a specified increase can be granted at the end of a stipulated period of satisfactory job performance, it is unwise to make commitments. Ambiguous promises lead only to employee discontent in later weeks. The average employee is far too likely to consider "perhaps" synonymous with "positively yes," particularly after time has elapsed and the details of his employment interview have become vague.

When a definite increase is promised at the end of a probationary period, it should be promptly granted without the employee's having to remind his supervisor. A notation of the promised wage increase should appear on the approved employment application or on the personnel requisition. This permits the wage-

and-salary section of the personnel department to remind the supervisor by initiating a special wage review shortly before the end of the probationary period.

AUTHORITY OF SUPERVISORS

Supervisors must be established as definite leaders of their personnel. The final decision in hiring personnel should be made by the supervisor for whom the employee will work. All recommendations for wage increases should either originate with the supervisor or receive his approval. Each general supervisor should have complete authority to dismiss personnel working under his direction and should heed termination recommendations of his subordinates. This policy places considerable responsibility upon each supervisor and provides the authority necessary to command the respect of his personnel. It will not *insure* the respect of the personnel, for that is gained only by demonstrated ability as a leader. Inspection management must guide and educate each supervisor in proper usage of his authority and assist in developing his capacity for leadership.

Management should never criticize a supervisor in the presence of a worker and should normally confirm the supervisor's decisions. If the supervisor's action is in error, he should be corrected in private and given an opportunity to rectify his mistake without loss of prestige. The supervisor guilty of frequent errors should be replaced, preferably, by dismissal rather than demotion. Few employees are able to accept demotion without ill feeling toward the company and loss of interest in their work.

The same general thinking should be followed in the relation between supervisor and worker. Supervisors who criticize or "bawl out" employees in the presence of their fellow workers are poor leaders indeed and have not learned that their job is to *guide* rather than to drive.

The chief inspector must avoid circumscribing the positions of the general supervisors forming his staff command. Each of these is responsible for the accomplishment of specified duties within scheduled periods, with the required degree of accuracy, in conformance with governing specifications, and within limits of established budgets. Efficient discharge of these duties requires

freedom of action to (1) determine detail methods best suited to accomplish the work, (2) obtain the required personnel, (3) assign personnel to the work for which they are best suited, and (4) dismiss unsatisfactory employees—these actions being subject, in all cases, to company standard practice and methods and to maintenance of lines of authority and discipline.

One of the most unpleasant duties of a supervisor is sitting in judgment upon an employee who has been accused of misconduct. It is vitally important to maintain a reputation for fairness in such cases. The Roman code of justice does not apply in this country, and the employee must always be considered innocent until proved guilty. Every effort should be made to investigate all circumstances fully, and little faith should be placed on hearsay evidence. An employee should never be accused, tried, convicted, and sentenced without ample opportunity to present a defense and confront his accusers. Any other course is a certain method of destroying employee morale.

EMPLOYEE MORALE

Departmental efficiency is directly proportional to employee morale, and this is dependent upon an intelligent operating program. Management must be certain that key personnel are fully informed of the nature and purpose of all work in progress and should confirm its confidence in their ability and discretion by delegating to each authority commensurate with his responsibilities. Nothing is more destructive to morale than denying necessary information and authority to subordinates. In fact, it is highly desirable to go beyond the negative approach of freely providing information only when requested, and to adopt a positive program of making certain that every member of the inspection department is fully aware of the purpose and importance of his job assignment.

Bethel, Atwater, *et al.*, in "Industrial Organization and Management,"[4] point out an excellent example of the importance of instructing inspectors in the relation of their particular operation to the end product:

[4] *Op. cit.*, Chap. XV.

One important point sometimes overlooked in the training of inspectors is that they should be instructed not only in the techniques of their particular inspection operation but also in its relation to the end product. That such training is not always given is shown by the true story of a new inspector in a large plant who, after a month's service, was questioned as to the kind of work he did. To this question he replied, "Oh hell, there's nothing to it. All I do is put a little metal thing into a gadget and watch the pointer. If the pointer stops at one place, I put the thing in one box. If it stops at another place, I put the thing in another box. Why, it's easy." Obviously what he was inspecting, the reason for the inspection, and why this material was segregated had never been explained to him. Such an explanation takes but little time and may seem unimportant, yet it often spells the difference between a conscientious and a disinterested inspector.

Foremost among causes of departmental discord is failure to adhere in all circumstances to the established line of authority. In no case should an inspection general supervisor issue instructions directly to a worker responsible to a subordinate. He should either transmit them through the worker's supervisor[5] or request that the worker be temporarily transferred for a special assignment. Everything possible should be done to maintain the position of supervisors. Only when the supervisor is unable to adjust the problem satisfactorily should the worker appeal to Inspection management. A worker who ignores this procedure by going directly to management should be promptly referred to his supervisor, without benefit of immediate decision or adjustment. In such cases management should follow up through the supervisor, to make certain that the matter is properly handled.

Other factors influencing inspection department morale are working conditions, wages, and adequate methods and equipment. In regard to these factors Bethel, Atwater, *et al.*,[6] state:

Just as a chain is only as strong as its weakest link, so also is the chain of quality in a product only as strong as the poorest inspector—hence the stress that is usually placed upon the maintenance of a high morale and degree of exactness among inspection personnel. Adequate

[5] For the purpose of this text, "supervisor" is considered to be synonymous and interchangeable with "foreman."

[6] *Op. cit.*, Chap. XV.

pay, light, airy, and clean inspection areas, inspection equipment always in good repair, intelligent supervision ready to back up the inspectors when they are right and to guide them properly when they are wrong—these are typical of the factors that maintain inspection morale.

PERSONNEL POLICY

A prerequisite to personnel control is a well-defined company policy that observes the fundamental rights of both employer and employee. This policy must be uniformly applied throughout the company, as exceptions and deviations will result in discord.

Inspection cannot create the company personnel policy, but it can assist management to establish a sound policy. Unless the company policy is healthy, it is difficult to achieve harmonious Inspection personnel control. In such cases Inspection management should concentrate upon development of a valid company policy, followed by the creating of specialized controls to handle personnel matters peculiar to Inspection.

Employees' Manual

After the basic company personnel policy is crystallized, it should be presented in an employee's manual and copies should be distributed to all company personnel. The publication of this manual, stating basic rules and regulations that govern the conduct and duties of *both* employer and employee, is a prerequisite to the maintenance of harmonious personnel relations. It need not be an elaborate, artistic publication. Even a brief mimeographed bulletin, establishing basic company policy and rules, is preferable to the confusion of a vague policy that is subject to daily interpretation and *misunderstanding* by both supervisors and workers. A large percentage of personnel grievances stems from deficient knowledge of company policy and regulations.

PERSONNEL RECORDS

Maintaining records of personnel transactions requires adequate records. Identical forms should be used throughout the company to record hiring, transfer, reclassification, and termination of employees. Development of detail procedures and rou-

tines governing their usage is a concern of the personnel department, although Inspection supervisors should be familiar with the general nature of satisfactory personnel records. Occasions may arise that require Inspection management participation in conferences regarding company personnel affairs. The subject of procedures and forms for personnel records is adequately covered elsewhere,[7] and their listing in this text would be repetitious.

Employee History Records

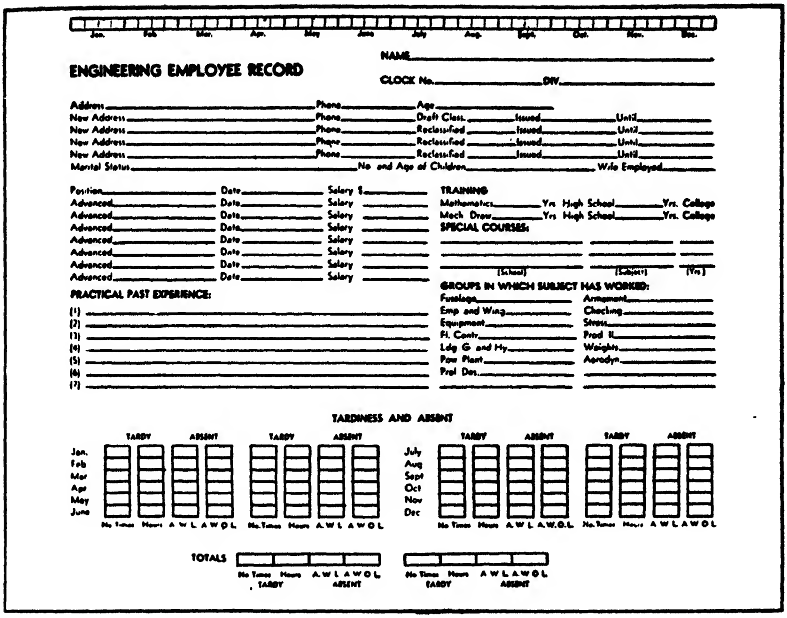
A complete history of each employee is essential to departmental personnel control. The history file for each employee, normally maintained by the company personnel department, should be briefly duplicated in the inspection department personnel records. This can be provided in the form of a summarized employee history record providing pertinent facts regarding each Inspection employee.

A typical departmental employee history record is shown in Fig. 4:1. This is intended for recording data relating to Engineering personnel, but it is suitable for Inspection use, with a few minor changes. It is an 8½- by 11-in. card having on one side a concise record of personal facts, experience, wage increases, and attendance. A date strip along the upper margin is flagged with colored signals, to indicate draft-deferment expiration, vacation, and next wage-review times. The other side of this record lists the employee's experience within the department, vacations, wage-review recommendations, and job-performance ratings. The space for the last item provides both for ratings recommended by the employee's supervisor and for corrected ratings approved by the chief inspector.

WAGE AND SALARY REVIEWS

Each employee should be periodically reviewed on the basis of job performance, to ascertain whether an increase in wage or salary is merited. The practice of hit-or-miss increases can-

[7] Bethel, Atwater, *et al.*, *op. cit.*, pp. 466, 473–479; Thompson, James E., "Engineering Organization and Methods," pp. 42–50, McGraw-Hill Book Company, Inc., New York, 1947.



Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec.

ENGINEERING EMPLOYEE RECORD

NAME

CLOCK No. DIV.

Address Phone Age
New Address Phone Draft Class. Issued Until
New Address Phone Reclassified Issued Until
New Address Phone Reclassified Issued Until
New Address Phone Reclassified Issued Until
Marital Status No. and Age of Children Wife Employed

Position Date Salary $
Advanced Date Salary
Advanced Date Salary
Advanced Date Salary
Advanced Date Salary
Advanced Date Salary
Advanced Date Salary
Advanced Date Salary

TRAINING
Mathematics Yrs. High School Yrs. College
Mech. Draw. Yrs. High School Yrs. College
SPECIAL COURSES:
(School) (Subject) (Yrs.)

PRACTICAL PAST EXPERIENCE:
(1)
(2)
(3)
(4)
(5)
(6)
(7)

GROUPS IN WHICH SUBJECT HAS WORKED:
Fuselage Armament
Emp. and Wing Checking
Equipment Stress
Fl. Contr. Prod. II
Ldg. G. and Hy. Weights
Pow. Plant Aerodyn.
Prel. Des.

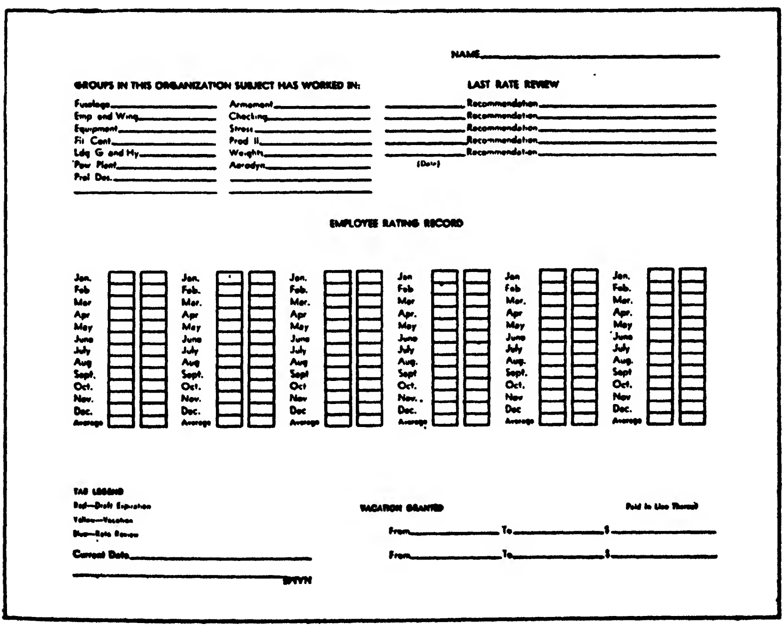
TARDINESS AND ABSENT

TARDY ABSENT TARDY ABSENT
Jan. Feb. Mar. Apr. May June
No. Times Hours A.W.L. A.W.O.L. No. Times Hours A.W.L. A.W.O.L.

TARDY ABSENT TARDY ABSENT
July Aug. Sept. Oct. Nov. Dec.
No. Times Hours A.W.L. A.W.O.L. No. Times Hours A.W.L. A.W.O.L.

TOTALS
No. Times Hours A.W.L. A.W.O.L.
TARDY ABSENT
No. Times Hours A.W.L. A.W.O.L.
TARDY ABSENT

(a)



NAME

GROUPS IN THIS ORGANIZATION SUBJECT HAS WORKED IN:
Fuselage Armament
Emp. and Wing Checking
Equipment Stress
Fl. Cont. Prod. II
Ldg. G. and Hy. Weights
Pow. Plant Aerodyn.
Prel. Des.

LAST RATE REVIEW
Recommendation
Recommendation
Recommendation
Recommendation
Recommendation
(Date)

EMPLOYEE RATING RECORD

Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec. Average

TAB LEGEND
Red—Draft Expiration
Yellow—Vacation
Blue—Rate Review

Current Date

SWVH

VACATION GRANTED Paid to Use Thereof
From To $
From To $

FIG. 4:1. Departmental employee history record.

SEE INSTRUCTIONS ON REVERSE SIDE

DATE________ SHIFT________

NAME________________

CLOCK NO.________________

CLASSIFICATION	RATE	GRADE

SIGNED________________

APPROVED________________
Dept. Head or Foreman

1	INTEREST IN WORK	12 Puts forth extreme effort to improve in all ways.	9 More than usual interest in work. Tries to improve	6 Tries to improve when told. Content "as is".	3 Occasionally careless. Mind wanders
		11 Always improving knowledge, trying to increase output	8 Usually interested in work and does it well	5 Shows lack of interest in work.	2 Dislikes work. Makes no effort to improve.
		10 Shows interest in work and strives to improve.	7 Likes work somewhat. Does it fair as a rule	4 Makes little effort to do better	1 Resents offers of advice or assistance.
2	APPLICATION	12 Constantly very busy. Never leaves work.	9 Usually busy. May require occasional prompting	6 Casually busy. Requires considerable prompting	3 Needs prompting continually. Away from work much.
		11 Always busy. Seldom leaves work.	8 Normally busy. Occasional prompting required	5 Does better only when told. Much prompting required.	2 Wastes time. Stares into space. Indifferent.
		10 Most always busy. Occasionally away from work	7 Fairly busy. Frequent prompting required.	4 Excessive prompting. Leaves work for long periods	1 Leaves work too much. Pays no attention to prompting
3	ABILITY TO LEARN	12 Brilliant. Learns very quickly.	9 Masters most situations very soon.	6 Learns somewhat slowly, But retains most knowledge.	3 Seems to comprehend instructions with difficulty.
		11 Is able to master practically all situations in short time	8 Learns fairly quick. Remembers instructions	5 Learns slowly. Occasionally forgets instructions.	2 Does not seem to understand instructions.
		10 Bright. Learns quickly. Retains knowledge	7 Average intelligence. Able to advance somewhat	4 Learns slowly. Forgets.	1 Absorbs practically no knowledge. Dull.
4	ACCURACY	12 Most accurate. Does work to very exacting tolerances	9 Few errors	6 Fair. Most work acceptable. Some rework	3 Much spoiled work.
		11 Very few errors. Does work to fairly exacting tolerances	8 Satisfactory. Usually turns out acceptable work	5 Occasional rejections	2 Work unsatisfactory. Many errors
		10 Very accurate. Does work to very close tolerances	7 Occasional rework necessary	4 Due to not using sufficient care, makes errors	1 Much loss due to rejections and rework.
5	SPEED	12 Very fast. Consistently a rapid worker	9 Production always high. Fairly fast worker	6 Scarcely keeps up with requirements.	3 Usually behind.
		11 Alway above average in daily production.	8 Occasionally somewhat ahead in work. Reasonably fast	5 Frequently behind in work.	2 Very slow. Makes no progress
		10 Fast. Usually turns out more than average day's work	7 Keeps up with production requirements. Average	4 Slow. Seems to be unable to keep up with work	1 Always far behind schedule
6	RELIABILITY	12 Most dependable. Always can be counted on	9 Fulfills requirements satisfactorily	6 Fair. But bears watching. May "slip up" on procedure	3 Apt to produce inaccurate work.
		11 Fulfills all requirements and usually more.	8 Dependable. Needs very little watching.	5 Requires much supervision.	2 Very undependable. Almost certain to waste time.
		10 Very dependable. Can safely be counted on	7 Seldom "slips up" on procedure	4 Cannot be depended upon to keep busy	1 Sure to spoil some work if not closely watched
7	INITIATIVE	12 Extremely original. Plans work to smallest detail	9 Takes hold of work very well. Requires little aid	6 Takes hold of work fair, but neglects caution	3 Requires much supervision.
		11 Original and resourceful. Plans work well	8 Takes hold of work well. Seek advice when in doubt	5 Strong tendency to risk making errors	2 Requires continual prompting to attend to business.
		10 Fairly original. Seldom requires instructing	7 Takes hold of work fair, but somewhat overcautious	4 Must be prompted often. Lets things slide	1 Too much supervision required.
8	JUDGMENT	12 Unusual sense of proportion.	9 Usually interprets orders and instructions correctly	6 May accept methods of procedure without question	3 Often attempts to "get by" with faulty work
		11 Seldom—if ever misinterprets orders or instructions	8 Usually able to determine good from bad methods	5 Frequent loss due to errors in judgement	2 Unable to judge good from poor work.
		10 Very good judgement. Usually does the right thing	7 Corrects faulty procedure during process as a rule	4 Apt to make wrong decisions regarding work	1 Takes wrong attitude when corrected
9	CONDUCT	12 Behavior perfect. Tries to get along with everyone.	9 Cooperates cheerfully with superiors	6 Obeys orders. Fair on rules. Cooperates reluctantly	3 Plays around. Interferes with work of others.
		11 Excellent cooperation with superiors	8 Observes company rules. Gets along with others.	5 Plays occasional pranks. May occasionally argue.	2 Disregards rules. Loaf with others. Quarrelsome.
		10 Good behavior. Considerate of others	7 Obeys orders without comment. Usually neutral	4 Frequently lax in observance of company rules	1 Argues with superiors. Antagonizes.
10	ATTENDANCE	12 No time off. Never late. Always on the job.	9 Rarely requests pass out. Only occasionally late	6 Some time off and occasionally late.	3 Gives too much attention to outside business.
		11 Never requests pass out. Never late. Seldom off.	8 Seldom off or late for work. Occasional pass out	5 Frequent pass outs. Frequently off or late.	2 Practically never on time. Too much time off.
		10 Little time off. Seldom late. Nearly always on the job	7 Frequent pass out	4 Much time off. Often late to work	1 Seldom on the job.
	TOTALS 12 11 10	EXCELLENT	TOTALS 9 8 7 AVERAGE	TOTALS 6 5 4 BELOW AVERAGE	TOTALS 3 2 1 DEFICIENT TOTAL

FIG. 4:2 (*a*). Job-performance rating form for nonsupervisory employees.

This card must be completed, signed, approved and returned to the Job Evaluation Department within 48 hours.

INSTRUCTIONS

Each employee must be carefully appraised and graded. For example; in the column at the left the first factor is "Interest in Work." To the right we find twelve sentences. Choose the one which best fits the employee and insert a cross (X) in the numbered square. Follow the same procedure for the other nine factors. Total each column, then insert the grand total in the lower right hand corner of card.

If the card is shown as a beginner indicate what the first classification should be by inserting it under beginner. If a reclassification is desired the same procedure is followed.

If a wage adjustment is not recommended, explain ______________________________

____

____

____

____

____

____

____

Signed ______________________________

FORM E 37 8M 3-48-102

FIG. 4:2 (*b*). Reverse side of job-performance rating form for nonsupervisory employees.

SUPERVISORY DEVELOPMENT REVIEW Date ____________

Dept. ____________________

Employee ____________________ Clock No. ________ Position ____________________

In conducting this review, be exact and impartial. Remember that you are making this review to let the employee know how he is regarded, and to serve as a basis for constructive suggestions. It should represent the views of the two persons immediately over him in line of authority. On the rating form below, judge this employee on the basis of work now being done.

		Poor 1	2	3	Fair 4	5	6	Good 7	8	9	Excel. 10	
LEADERSHIP and EMPLOYEE RELATIONS	Disposition											
	Tact and diplomacy											
	Respect for subordinates											
	Regard for Employee Problems											
	Disciplinary Control											
	Handling of grievances											
	Personal appearance											
	Social conduct (deportment)											
	Utilization of employee's abilities											
	Delegation of authority											
	Gives credit where due											
	Development of subordinates											
	Promotion of goodwill											
	Organizational ability											
DEPENDABILITY and JUDGMENT	Interest in work											
	Ability to get all facts											
	Ability to weigh and decide											
	Judgment											
	Acceptance of criticism											
	Ability to follow instructions											
	Ability to assume responsibility											
	Follow-through											
INITIATIVE and RESOURCEFULNESS	Development of new ideas											
	Energy and aggressiveness											
	Ability to make decisions											
	Ability to get results											
	Application of new techniques											
	Ability to think for self											
KNOWLEDGE	Job Knowledge											
	Knowledge of Company policies											
	Advancement of knowledge of job											
	Attitude toward knowledge of others											
	Ability to inform others accurately											
	Solution of job problems											
COORDINATION and COOPERATION	Attitude displayed with others											
	Ability to maintain harmony											
	Acceptance of decisions											
	Appreciation of all problems involved											
	Coordination with other groups											
	Cooperation with others											
PLANNING COSTS STANDARDS	Housekeeping											
	Ability to meet schedules											
	Care of equipment											
	Planning											
	Accuracy											
	Ability to reduce costs											
	General workmanship standards											
	Enforcement of safety regulations											

REMARKS: ____

Rated by ____________________ Checked by ____________________ Date ____________

Return to: *Wage & Salary Administration Division, Industrial Relations Department.*

E-108

FIG. 4:3. Job-performance rating form for supervisors.

not be tolerated, and it is necessary to provide a simple, effective method of reviewing each employee at specified intervals. Frequency of review is governed by company policy, union contracts, or a combination of both; but in all cases it should be definite and understood by all employees. All job-performance ratings should be made by the employee's immediate supervisor

(usually a leadman), subject to approval of a general supervisor and the chief inspector.

The employee performance rating form shown in Fig. 4:2 is for nonsupervisory personnel and provides 12 variations in each of 10 basic factors. A cross is inserted in the numbered square opposite the condition that best describes the employee's performance. Each column is totaled, and a grand total is entered in the lower right corner of the card. This is the employee's performance rating and determines the advisability of an increase in pay. An employee failing to receive a rating of 95 or better rarely merits an increase.

A similar performance-rating method is used for supervisory personnel (see Fig. 4:3), except for rearrangement of data on the form. Emphasis is placed on leadership, cost consciousness, and employee relations. A score of 375 or better is usually necessary to merit a salary increase.

INSPECTION JOB DESCRIPTIONS AND EVALUATIONS

Effective hiring, transfer, and upgrading of employees require that carefully prepared, standardized descriptions and evaluations be prepared for each job in the inspection department. Without this tool of personnel control such matters must be left to the vagaries of opinion and prejudice, and unnecessary personnel problems are certain to arise. This subject is discussed in detail in Appendix I.

CHAPTER 5
STANDARDS

Standards are required to govern methods and procedures, repair and salvage, and inspection operations. A method of releasing this information to all concerned should be developed, followed by establishment of a system to make certain that copies of revised standards reach all recipients of the original information. One person in the Inspection office should be designated to control preparation, distribution, and revision of standards.

When standards are carefully prepared, when they are comprehensive in nature and faithfully observed, there will be no need for inspectors' spending time debating the proper method of inspecting an item or the correct procedure for a particular condition. Standards should be published in suitable form and copies distributed to all personnel affected by their provisions. The information contained in these standards should be followed without deviation other than changes authorized by the Inspection office in cases where standards are found to be deficient.

A standard found undesirable, inadequate, or in error should be promptly corrected through issuance of a revision to eliminate the deficiency. Chronic violations due to uncorrected deficiencies cannot be tolerated, as the entire purpose of standards is then defeated. Standards are intended to assist, rather than confuse, the functioning of Inspection by providing information that eliminates operational problems and duplication of effort.

CLASSES OF STANDARDS

The standards normally used by Inspection relate to (1) policy and procedures affecting both Inspection and other departments, (2) policy and procedures primarily affecting Inspection, (3) inspection methods, (4) standard repairs, and (5) standard-

ized company parts and designs. These are normally issued as separate publications, identified as (1) standard practice instructions, (2) inspector's manual, (3) inspection specifications, (4) standard repair manual, and (5) standard-parts handbook.

CONSOLIDATED VULTEE AIRCRAFT CORPORATION
VULTEE FIELD DIVISION

DIVISION STANDARD PRACTICE

NUMBER 2 ISSUE 7
SUPPLEMENT -- ISSUE
PAGE 1 OF 5 PAGES
DATE ISSUED

SUBJECT: MASTER AUTHORIZATION SYSTEM

Please destroy all copies of D.S.P. 2, issue 6, dated November 12, 1943. This issue 7 obsoletes issue 6.

I PURPOSE

To establish the procedure for requesting, obtaining approvals for, preparing and distributing Master Authorizations.

II DEPARTMENTS AFFECTED

A. All departments of Vultee Field Division

The following departments are affected by additional instructions:

B. Plant Engineering
C. Industrial Engineering
D. Accounting
E. Contract

III PROCEDURE

A. All departments of Vultee Field Division (General Office Depts.' See Suppl. 2)

1. Scope, Classification and Method of Making Request

The Master Authorization System, through the use of the Master Authorization (form #102-19-1), shall control work performed and money spent at Vultee Field Division and shall cover the following:

a. Sales Contract M.A. — A Sales Contract (Production) M.A. is one issued to cover all items of direct cost which will be charged against a sales contract.

On the basis of a customer's purchase order or sales contract executed by the Contract Department, a M.A. shall be issued by the Master Authorization Group according to Supplement 1 of this instruction.

b. Capital Expenditure M.A. — A Capital Expenditure M.A. shall be required to cover the purchase, construction, sale, trade-in, transfer or scrap of any item of machinery, equipment, or other facility, regardless of amount, also for the installation charges on equipment transferred from another division.

PREPARED BY H. K. Tooter DATE 1-27-45

APPROVED BY G. A. Irvin
G. A. Irvin

AUTHORIZED BY Carl ?. Cooslow
DIVISION MANAGER

151-88-2

FIG. 5:1. Standard practice instruction.

Standard practice instructions are usually issued by the company industrial engineering or methods department and cover basic company policy and interdepartmental functions. These standards primarily concern department heads responsible for their conformance, and copies are normally issued only to key personnel.

The inspector's manual provides details of the basic operation of the inspection department, and copies are normally supplied to each inspector. Copies of inspection specifications, standard repair manuals, and standard-parts handbooks should be available to all Inspection personnel. Individual copies should be supplied to inspectors having need for frequent reference to these publications.

Company and Departmental Standards

The relationship of company and departmental procedures can be demonstrated by examination of various classes of personnel procedures. It is important that all basic personnel controls affecting the entire company be prepared as company standard practices. Such matters as absence from work, leaves of absence, leaving plant during working hours, handling of time cards, property passes, overtime authorization, and changes in working hours are in this category.

On the other hand, items such as loss of inspection stamps, inspection manuals, or instructions are affairs that principally concern the inspection department. The policy and procedure affecting matters of this nature should be issued to all Inspection personnel in the form of inspection departmental instructions, contained in the inspector's manual.

Other procedures may be somewhat marginal in nature. The recording and control of company and personal tools is in this category. While all direct labor employees may be affected to some degree by this procedure, it probably affects inspectors to a greater degree, owing to the greater number of precision tools required for inspection work. In these cases the inspection department conforms to the general company procedure but may find it desirable to reprint the company procedure as a portion of the inspector's manual.

ESTABLISHMENT OF BASIC PROCEDURES

The basic procedures that must be established to insure successful operation of an inspection department relate to

Organization	Changes
Personnel	Gages and instruments
Planning	Physical-inspection methods
Costs	Salvage
Records	Analysis and research

These are considered in other chapters, in which practical, proved procedures for accomplishment of each are given. The detail methods given may not be suited to every inspection department, but the general pattern will be applicable in practically all cases.

Considerable judgment, discretion, and patience are necessary during selection, development, and application of inspection procedures. Each proposed procedure must satisfy all possible contingencies, and its operation must be compatible with existing conditions and facilities. In each case the procedure must provide adequate control of inspection action without introducing expensive or burdensome complications.

Inspection procedures should be contained in the inspector's manual. Each procedure should be created to control a basic operational function in the most efficient manner. Prior to establishing a procedure, it is necessary to analyze the nature of the function involved, its effect upon Inspection and other departments, facilities available for its operation, and existing methods used to effect its working.

Whenever practicable, a considerable portion of the existing methods should be incorporated in the new procedure, in order to avoid drastic changes that may result in disruption of the function involved. Improved methods should be introduced as smoothly as possible, so that the effect is one of continuous improvement in departmental efficiency rather than one of abrupt dislocation.

Following formulation of a procedure, it is advisable to call a meeting of all supervisors who will be affected in any manner by its provisions. The proposed procedure should be thoroughly

discussed to locate and correct defects and to effect a thorough understanding of its operation and necessity. Full advantage should be taken of constructive criticism. When such meetings are properly handled, the supervisors will feel that they have played a part in creating the procedure. This will help toward securing the necessary cooperation during application of the procedure.

The person responsible for establishing procedures must be able to justify the need for every provision and rule. Personnel responsible for the application of procedures cannot be depended upon to adhere consistently to their provisions unless the necessities for them are clearly understood. In every case the major problem in establishing inspection procedures is not preparation of a practicable, efficient method but rather obtaining the full cooperation of all personnel responsible for successful operation. Unless this is accomplished, the best procedures will fail. The importance of this factor must not be underestimated, and every possible step must be taken to overcome the normal human aversions to change of any kind and to regulation of any nature.

INSPECTOR'S MANUAL

The completed procedures should be issued, after review and approval, as a portion of the inspector's manual (see Fig. 5:2), with copies distributed to all inspection personnel. The inspector's manual then becomes the standard, governing all procedures, policies, and rules relating to the operation of the inspection department. Whenever a question arises regarding the proper handling of a certain situation, it is necessary for the person responsible for a decision only to refer to the inspector's manual.

It might appear, upon superficial examination, that an inspector's manual would be required only in large inspection departments and that small departments could depend upon the chief inspector or upon a general supervisor to define verbally departmental methods, policies, rules, and procedures whenever the need arose. This is not considered desirable, as conflicting decisions may be given when long periods elapse between recurrences of similar questions. Also, too much of the

APPROVALS	INSPECTION DEPARTMENT MANUAL	No. 4-1 Issue: A
Chief Inspector s/ W. W. Johnson Gen Man. s/ C. S. Reem		Effective Date 14 Feb 49 Ref. – – – Page 1 of 8 Pages

SUBJECT: COMPANY INSPECTION STAMPS

1. Application of Stamps -

a. The application of any stamp (other than rejection, and with held for salvage) to any item and/or accompanying documents signifies that the inspector applying the stamp certifies that the item has been produced in accordance with applicable drawings and specifications — or is acceptable under an existing Minor Discrepancy Report, Standard Repair, Engineering Deviation, or a Salvage Board disposition.

Application of a stamp opposite an operation entry on a shop order signifies that the operation was in accordance with applicable drawings and specifications.

b. Stamps must be applied to all items and/or accompanying documents in a manner that is clearly legible.

c. Steel stamps shall not be applied to:

(i) Bearing surfaces.
(ii) Non-ferrous material thinner than 0.020 in.
(iii) Highly stressed areas or items.
(iv) Any material harder than Rockwell 43-C.

and shall be placed in locations where:

(i) Subsequent operations will not deface or remove the stamp impression.
(ii) The stamp impression will not cause immediate or subsequent damage — such as cracks resulting from a steel stamp impression on a bend-line.
(iii) The stamp impression will be adjacent to the item's part number if possible, and always in a location visible after the item is joined to its next assembly.

d. Rubber stamps shall be used:

(i) For stamping Inspection documents.

FIG. 5:2. Inspector's manual.

supervisor's time may be consumed in conveying instructions on routine matters. The time spent in explaining a particular method or policy *once* is not much more than that required to prepare the information as a portion of an inspector's manual, which can then be made available to all concerned as a means of answering the particular question permanently.

The variety of information that can be placed in an inspector's manual is almost limitless, but it should be confined to methods that the inspector is required to follow and to reference material that is frequently needed in inspection work. The following outline provides an indication of subjects for an inspector's manual suitable for a majority of manufacturing plants.

Section 1. *Use of the Manual*

Purpose. Issuance of manual. Indexing system. Preparation, publication, and distribution of manual information. Revisions of manual. Responsibility for use of manual. Other inspection standards.

Section 2. *Organization*

Company organization. Inspection organization. Organization of other departments. Organization charts. Basic functions of inspection groups. Flow of inspection work. Location of inspection areas.

Section 3. *Personnel*

Duties of inspection personnel. Authority and responsibility of supervisors. Wage and salary reviews. Absence from work. Leave of absence. Leaving factory during working hours. Loss of inspector's manual, or other inspection standards. Material passes. Personal property in the factory. Time cards. Company and personal tool procedure.

Section 4. *Inspection Stamps*

Types of stamps and their usage. Assignment of inspection stamps. Unauthorized use of stamps. Damaged stamps. Loss of stamps. Surrender of stamps upon terminating employment.

Section 5. *Sources of Inspection Data*

Engineering drawings and specifications. Purchase orders. Shop orders. Inspection standards. Standard repair manual. Change control procedure.

Section 6. *Recording Inspection Action*

Receiving report. Shop order. Rejection notice. Inspection flow record. Inspection log.

Section 7. *Rework, Rejection, and Salvage*

Deviations from specific requirements. Deviations from good workmanship. Rework procedure. Determining need for rejection. Use of rejection notice. Use of minor discrepancy notice. Salvage-board procedure. Disposition of rejected parts found in production.

Section 8. *Receiving*

Function. Forms used. Operating plan. Detailed procedures. Reports required. Inspection equipment. Records. Typical examples of defective items. Receiving inspection bulletins and specifications.

Section 9, etc.

(Additional sections as required, following the outline of section 8, and providing detailed information for fabrication, assembly, shipping, tooling, inspection laboratory, and the like.)

Appendix I. *Reference Data*

Publications available in inspection library. Rivet and bolt standards. NC- and NF-thread data. Pipe-thread data. Stud-thread data. Straight- and taper-pin data. Drill and countersink data. Wood screws. Conversion factors. Decimal equivalents. Trigonometric formulas and functions. Summary of material and process requirements.

If a provision of the inspector's manual (or other inspection standard) is found undesirable or in error, a revision to correct the fault should be promptly issued. The purpose of inspection standards is to assist, rather than hinder, departmental operations, and these should never become an inflexible book of rules. When a particular standard is revised, it is necessary to make certain that corresponding revisions are made in all related publications and that copies of the revised material are promptly furnished to all manual holders. The original issue of a standard can be identified as "issue *A*" and its revisions by change letters, beginning with issue *B* as the first alteration.

Verbal deviations from the inspector's manual cannot be permitted, as this will lead to the entire inspection standards system's falling into disrepute. In cases in which immediate change or correction of a standard is imperative, an amendment stating the nature of the revision should be issued to all Inspection personnel. Revised manual pages incorporating the amendment should be prepared and distributed as soon as possible.

The inspector's manual is issued to establish methods and pol-

icies that are considered best for the interest of the company and of all Inspection employees. Hence, it is necessary for its provisions to be faithfully followed. Each supervisor should be held responsible for his employees' following all instructions relating to the activities under his direction.

STANDARD-REPAIR MANUAL

Analysis of salvage-disposition records for a given product over a sufficient period will reveal many cases of rejected items salvaged through similar or even identical special repair methods. The expense of individual salvage action on these cases can be eliminated by establishing a standard-repair manual, listing approved repair methods and the limits of damage acceptable for repair.

The inspector who discovers a defective item can then avoid the necessity of issuing a rejection notice and forwarding the item to the salvage committee when the defect is within the limits of a standard repair. In such cases the defective item can simply be returned to the proper department, with instruction to "repair in accordance with standard repair No. XXXX." Upon the repair's having been satisfactorily accomplished, the item can be accepted in the usual manner, with appropriate notation on the inspection flow record and the shop order.

Standard repairs should be approved by Engineering and Inspection, and sometimes by the customer's representative. A standardized form should be followed in the preparing and issuing of standard-repair data, and each should be assigned a number for reference purposes, similar to the following example appearing in the standard-repair manual of the Airplane Division of Fairchild Engine and Aircraft Corporation:

Standard Repair 2–31

Model: All

Subject: For repair of general damage to thin aluminum sheet, occurring most commonly in skin covering. Application limited to open-sheet-section areas where extent of damage is located not less than 2 in. from adjacent structure.

Approval: AAF inspection required prior to use, and/or Navy.

Authority: The following repair may be authorized by F.A. Inspection leadman or foreman.

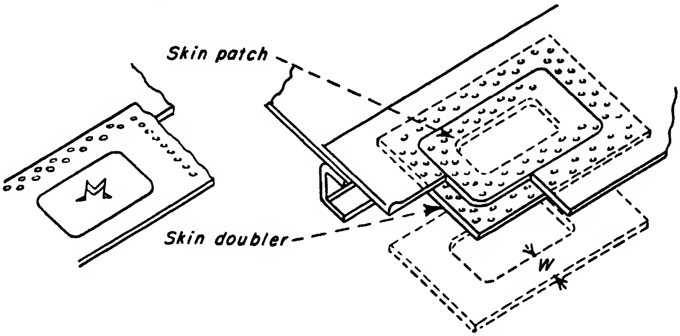


FIG. 1 FIG. 2

Required: One skin patch, one skin doubler.

Material—same type and thickness as damaged sheet. Size—skin patch cut to fit cutout of damaged area. Doubler to be larger than cutout to accommodate rivets to sheet with proper edge distance. See Procedure 3. Form patch and doubler to contour, if necessary.

Procedure:

1. Remove damaged area by cutting a circular or a rectangular hole; minimum corner radii for rectangular cutouts to be ½ in. Smooth all edges to remove burrs.
2. Fit skin patch to cutout as closely as possible and locate position of doubler to provide equal overlap at all edges of cutout.
3. Attach doubler to sheet and skin patch to doubler by riveting as shown in Fig. 2. All attaching rivets must be identical in type, size, and spacing as the most closely spaced splice rivets attaching the damaged sheet panel to adjacent structure; all rivet edge distances to be taken accordingly.

Note: Central area of skin doubler may be removed for weight saving provided that width of doubler is not less than twice overlap to sheet (dimension *W*, Fig. 2). Generous radii must be provided for cutout in doubler.

INSPECTION SPECIFICATIONS

In the manufacture of precision articles, the requirements for inspection often become lengthy and complex, and it is undesirable to depend upon verbal instructions and memory for the accurate accomplishment of inspection operations. Inspection specifications, issued to detail the procedure for examining com-

PART NUMBER

OPERATION SHEET

CARD NUMBER

Receiving, Fabrication and Sub-Assembly Inspection

VENDOR'S PART NUMBER	VENDOR	BUYER	QUALITY STANDARD

Material Specification	Procurement Specification	Manufacturing Specification

TOOLS REQUIRED	
Thread Gauge | Male	
Size | | Female	
Ring Gauge	
Plug Gauge	
Height Gauge	
Surface Plate	
Micrometer | Inside	
Size | | Outside	
Snap Gauge	
Drill	
Special	

HARDNESS TEST	
Rockwell Min	
Scale | Max	
Durometer Shore	
Barcol	
Webster	
Percent Required	

LABORATORY TEST	
Chemical | Qualitat	%
| Quantitat	%
Physical	%
Salt Spray	%
Identometer	
Spectrograph	
Specification #	

SPRING TEST	
Compression	#
Tension	#

MAGNETIC INSPECTION	
Circular	%
Bipolar	%
Steel Stamp	%
Rubber Stamp	%
Orange Dye	%
None Required	

TANK TEST	
Leak Test	
p s i	
Flow Test	
g p h	
Lube #	
Functional	
Operation	
P T Stamp	

See following Procedure Manual	
Hydraulic Test	Page Number
Electric Test	Page Number
Instrument Test	Page Number

REMARKS

RECEIVING HISTORY						
Date	Quan Recd	Quan Rej	P. O.	R. R.	I. R.	Insp.

FIG. 5:3. Inspection operation sheet.

plex items, are an excellent means of insuring proper inspection in all cases.

Inspection specifications can be grouped into three broad classifications of (1) operation sheets, (2) methods bulletins, and (3) production-inspection specifications. Operation sheets are prepared to systematize precise inspection operations, such as

INSPECTION OPERATION SHEET

Check Work for Conformance to the Indicated Requirements

GENERAL
Quality of workmanship
For evidence of previous inspection
Standard parts conform to B/P Spec.
Bolts, nuts and fasteners secure and safe
Torque correct on all bolts and hose clamps
Rivet pattern, type, size, correct
Check A.P.S. against blueprint
Lube correct on all threads and valves
Dissimilar metals properly insulated
Part number, dash, PT, HT, M, or Salvage Stamp O. K.
Look for possible mechanical defects
Finish correct as specified below:
Anodic ☐ Zinc ☐ Etch ☐ G. Prime
Cadmium ☐ Enamel ☐ A. Prime
Strip Test Minimum Thickness
Other:

DETAIL AND SUB-ASSEMBLY
Correct material per B/P or traveler
Parts conform to template or fixture
Location of holes, bends, cutouts O. K.
All bend radii correct—corner relief O. K.
Waterseal correctly applied
Edge distance acceptable, rivets and bolts
All steel parts removed prior to anodize
No threads in bearing
Previous inspection of welded parts
No lost motion (control systems)
Spotwelding acceptable
Material cleaned prior to spotweld

DETAIL AND SUB-ASSEMBLY (Contd.)
Spotweld pull test, 3 spot O. K.
Spotweld pull test, 5 spot O. K.

Process (mark in sequence as 1 2, 3, etc.)

	Oil Drain & Seal		Heat Treat		Pickle
	Paralketone		Arc Weld		Dow
	Passivate		Gas Weld		Anneal
	Neutralize		Parkerize		Bake
	Sand Blast		Normalize		Braze
	Copper-Braze		Metal Spray		Degrease
	Silver Solder		Bright Dip		Iridite

ELECTRICAL SUB-ASSEMBLY
Wire conect size and numbered O. K.
Terminals correct size and secure
Lacing tight and spaced O. K.
Boggles where needed
Correct plug used, ring out and hook up O K.
Terminal strips intact and installed O K.
Conduit properly installed
Flex conduit beaded and secure
Instrument correct as to size, type, etc.
Drain holes in stalled as per specification

TUBE BENDING
Flares, beads, tube size O. K.
Tube fittings installed correctly
All bends satisfactory
Color bands correct and installed O. K.
Tube ends sealed

SKETCH OR REMARKS

Concentrate on your work—bear in mind that the parts you inspect must perform a specified function in the assembly

FIG. 5:3. Inspection operation sheet. (*Continued.*)

those encountered in receiving and subassembly work, where the inspection procedure is brief but exacting.

Methods bulletins are issued to detail exacting inspection procedures that are too involved to permit adequate description on an operation sheet. Production-inspection specifications are prepared to describe the correct sequence of inspection, assembly, and test for highly complex items, and often relate to components purchased from vendors. These specifications are used as guides by *both* Inspection and the factory departments, providing detailed instructions for the entire handling of the item

through receiving-inspection, assembly, installation, and final assembly testing. Examples of inspection-methods bulletins and production-inspection specifications will be found in Appendix II.

COMPANY STANDARD PARTS AND DESIGNS

Company standard parts and designs are those that have been standardized to eliminate unnecessary duplication of engineering work and blueprint release. A standard part differs from other parts in that it is not identified with any one particular model but is (or can be) used universally over a range of models.

A standard design establishes a uniform method of accomplishing a certain fabrication or assembly operation and simplifies drawings by eliminating repetition of elaborate notes. Examples of one type of standard design are lightening holes, stiffening beads, rivet-installation data, and electrical-cable-assembly information. A second type of standard-design drawing is used to show "envelope" dimensions for design components standardized by a recognized industry committee or governmental agency.

Drawings of company standard parts and designs are normally contained in a standards handbook issued by the engineering department. These are referred to whenever the drawing for an item being inspected calls out a standard part or design.

OBSERVANCE OF STANDARDS

Standards are intended to simplify and increase the accuracy of inspection activities. These objectives will be achieved when all inspection personnel are thoroughly "sold" on the necessity of strict observance of standards. This can be insured through a combination of educating inspectors to understand the value of standards as an aid to inspection work and clearly defining the responsibility of Inspection personnel for the observance of standards.

All general supervisors should make certain that supervisors under their jurisdiction have all standards applicable to the work of each, maintain these in an up-to-date condition, and acquaint all inspectors with standards requirements. Keeping standards up to date is a matter that should not be left to individual inspectors using the data. Experience has shown that

personnel using standards books, drawing prints, and other reference data are prone to neglect prompt insertion of revised pages, change notices and the like, with the result that the reference material quickly becomes semiobsolete.

This problem can easily be solved by assigning one person in the inspection office the responsibility for keeping all standards up to date. This person has the responsibility of receiving all new and revised standards, obtaining a sufficient quantity of each, and immediately placing these in the standards books—this to be followed by removal and destruction of superseded pages (except those contained in record copies). New and revised pages should be called to the attention of the holder of the book affected, and his inspection stamp should be affixed to the pages as evidence of knowledge of the revision.

Each inspection supervisor should review all new and revised standards, to determine those applicable to the work performed by his group. A copy of each applicable standard should be circulated among his personnel to be read and stamped by each, and then returned to the supervisor for filing as a *permanent* record. A periodic check should be made of all standards books used by his inspectors, to make certain that all are up to date, understood by the personnel, and properly stamped to certify that each was read by the inspector holding the book.

Whenever a supervisor finds that a standard is incorrect, incomplete, or inadequate he should immediately send a written request to his general supervisor for the necessary correction, addition, or revision. General supervisors should not have the authority to reject requests for standards alteration originating with their subordinates. Instead, their action should be confined to analyzing the request and forwarding it, with comments, to the chief inspector.

Inspectors should analyze and thoroughly understand each standard received from their supervisor. Any provision that is not entirely clear, either as to its necessity or its meaning, should be discussed with the supervisor. The inspector should affix his acceptance stamp to both the file copy and his personal copy of each standards page, and should refer to the information contained therein whenever he is accomplishing work relating to the standard.

CHAPTER 6
RECORDS

A variety of detail records may be maintained by an inspection department, but the basic requirements for recording Inspection action involve accurate information regarding (1) the status of each end item accepted by inspection and (2) the level of quality achieved by the manufacturing departments.

The status of an end item involves recording the acceptability of all detail parts and assemblies involved in its construction and the approval of final-assembly and operational testing. Accurate analysis and interpretation of the levels of quality achieved by the manufacturing departments permits diagnosis and correction of production deficiencies, improvement of product quality without increasing costs, and reduction of rework and scrap.

STATUS OF END ITEMS

The importance of accurate knowledge of the status of each completed end item varies according to the nature and use of the product. It is obviously of small importance to know the status of each end item in the case of manufacturing automobile wheels. The only important consideration in such a case is that all completed wheels are acceptable to final inspection, prior to shipment.

On the other hand, a company manufacturing a complicated, precision end item, such as electric-generator sets, automobiles, or airplanes, must not only consider the problem of producing an article that will meet the customer's requirements, but also that of maintaining individual identity for each end item to permit rapid, accurate handling of customer service complaints, requests for data, and spare-parts orders. It is then important to know the exact status of each completed end item, including

all engineering changes, salvaged parts, and repairs incorporated therein.

A satisfactory method of maintaining an exact status record, when this is considered necessary, is assignment of serial numbers to each end item, and use of individual *inspection logs* to record pertinent data relating to each end item.

INSPECTION LOG

The inspection log is the medium for obtaining a complete historical inspection record of the construction, operational testing, and delivery of end items. A separate inspection log is prepared for each end item, identified by its serial number, and should contain the following minimum data:

1. A file of completed operation inspection lists (see Chap. 2)
2. Copies of assembly shortage records
3. Minor discrepancy reports
4. Copies or records of rejection and rework action
5. Final assembly unsatisfactory reports (commonly referred to as "squawk sheets")
6. Change check-off list (see Chap. 2)
7. Index of data contained in inspection log

REJECTION AND REWORK RECORD

End-item No.________ Model:________________

(1)	Rejection Notice No.	Part No.	Part Name:	Qty:	Sta No.	Date:
Disposition:				Date:	Shop:	Insp:
(2)	Rejection Notice No:	Part No:	Part Name:	Qty:	Sta No.	Date:
						Insp:

FIG. 6:1. Rejection and rework record.

The inspection log begins as a folder issued by either Manufacturing Planning or Inspection upon the end item's reaching the first station in final assembly. Only in rare instances is it

advisable to maintain logs for major subassemblies, as the actual serial number end item that these will join is difficult to determine. In a few cases, such as military aircraft manufacture, this is done by assigning serial numbers to major subassemblies, and maintaining logs for each. Upon these large components' reaching the first station of final assembly, the subassembly logs are added to the inspection log for the end item.

Inspectors are responsible for the custody of all inspection logs in their work areas. Their activities in completing each log in-

ASSEMBLY UNSATISFACTORY REPORT
(Squawk Sheet)

End-Item No.______ Model:______ Dept:______ Sta:______

Squawk No.	M	E	Description	Corrected		
				Date	Shop	Insp:

Note: M indicates mechanical squawk; E an electrical squawk

FIG. 6:2. Final-assembly unsatisfactory report.

volve certifying the completion of required operations; recording all rework, rejection, repair, deviation, and discrepancy data; accurately recording all data in the log index; forwarding the log to the next inspector upon the end item's moving out of their area, and finally forwarding the completed log to the inspection office upon the end item's receiving final acceptance. Inspectors should issue a rejection notice on an end item delivered to their area without its inspection log.

Completed inspection logs delivered to the inspection office are examined by the quality-control engineering group for completeness and for compilation of statistical data; and then are stored in a permanent file.

A daily check should be made by each Inspection supervisor to ascertain that all logs in his area are properly maintained. If the daily check reveals loss of an inspection log, the supervisor should immediately issue a rejection notice against the end item covered by the missing log. If the missing log cannot be located, a duplicate should be issued, and this should be followed

by reinspection of all work accomplished up to that point, with notation of the exact nature of the reinspection entered in the new log.

SPECIAL RECORDS

Various records are required in the accomplishment of physical inspection of manufacturing operations, and these are described in following chapters. In addition, there is need for certain special records maintained in the inspection office for control purposes. Among these are personnel records, attendance and tardiness records, list of inspection-stamp and manual assignments, and quality-control records.

Inspection-stamp Assignments

A list of inspection-stamp assignments should be prepared and issued to all inspection personnel. This should list the type and the serial numbers of all stamps assigned to each inspector, together with his employee number and work station. This list should be maintained in an up-to-date condition by issuing revised pages whenever an assignment change occurs.

A record of stamp assignments is useful in a variety of ways. It provides a means of accurate periodic inspection of stamps and a check on the return of proper stamps upon the termination of employment. During inspection examinations it provides a rapid means for an inspector's locating a suspicious item, to contact the person responsible for earlier inspection acceptance. The inspector responsible for acceptance or rejection of any item or record bearing an inspection stamp can be immediately identified through reference to the assignment record.

Corrective-action Request

Another record often used throughout the manufacturing departments by Inspection is the *corrective-action request.* This is issued by Inspection to identify accepted parts which are of marginal quality, as a result of inferior workmanship, tooling, production methods, or design; but which cannot undergo rework without damage. Issuance of a corrective-action request against the marginal items is Inspection's means of notifying all parties

concerned regarding the nature of the deficiency, and of requesting prompt corrective action to avoid rejection of similar items encountered in the future.

A reasonable time must be allowed for correction of the deficiency when tooling, methods, or design are involved; and a time or serial-number limit should be shown on the request.

Corrective-action requests are issued against the first item upon which a marginal condition is encountered and upon subsequent production lots or assemblies, up to the effectivity for correction shown on the original request, unless corrective action is accomplished prior to the established effectivity.

Issuance of a corrective-action request does not constitute a stop-work or rejection order, and additional work is not required on the items listed on the request.

Copies of the corrective-action request should be sent to Manufacturing Planning, the salvage board, and the quality-control engineering group of Inspection. A suitable form for this purpose should provide the following information: (1) department where action is necessary; (2) part number and name; (3) responsibility for deficiency; (4) corrective action required; (5) effectivity (When workmanship alone is involved, this will be through agreement with shop foreman affected; when other cause, through agreement with Manufacturing Planning.); (6) signatures of originating inspector, his supervisor, and shop foreman or planning supervisor concerned with establishing effectivity; and (7) date of issuance.

The quality-control engineering group should investigate all outstanding corrective-action requests once each week, to ascertain whether the requested action is being accomplished. When it is definitely determined that the requested corrective action is not being taken, quality-control engineering should contact the proper department head to obtain immediate action. If a satisfactory agreement cannot be reached with the department head, the problem should be referred to the chief inspector.

GAGES AND INSTRUMENTS

An adequate gage-and-instrument record is mandatory in every plant engaged in precision manufacture. This provides not

only an inventory, but also a record of periodic inspection of all gages and instruments, showing the actual dimensions found at each examination.

This record should be maintained by the gage-and-instrument inspection group; when properly established and used, it becomes their basic tool in maintaining all gages and instruments within required limits of wear and accuracy. A detailed discussion of this subject appears in Chap. 15.

INSPECTION STATISTICS

The degree and nature of inspection statistics to be maintained depend upon the type of product and the attitude of company top management. In all cases it is highly desirable to maintain records of trends in rework, rejection, salvage, repair, and scrap. These can be maintained on a departmental basis, according to class of work and nature of defect; and they provide a valuable guide in diagnosing and eliminating causes of excessive rejections and scrap.

When the nature of the product is such that its failure will not endanger life, it may be desirable to apply statistical quality control methods. Even with a highly critical product, such as aircraft, there are many items that can fail without endangering life, and the application of statistical methods to these items is worthy of study.

STATISTICAL QUALITY CONTROL

Statistical quality control is simply a process of sampling inspection, based upon mathematical analysis of probable quality variations in the product. Its use can eliminate needless inspection and, through analysis of inspection results, identify quality variations as being either normal or abnormal. This permits immediate location of trouble spots and avoids unnecessary tampering with the production process. The latter factor is quite important, as needless changes, made in an attempt to correct temporary conditions, will only tend to introduce additional variables affecting product quality.

Mr. James R. Crawford, a research economist for the Stanford

Research Institute, presents the elements of statistical quality control as follows: [1]

The methods for establishing statistical quality control over a process are based on the premise that the variation found in successive small samples taken from the production line is analogous in all respects to the variation found in small samples taken at random from a normally distributed static universe. The methods are designed to furnish the maximum amount of information from any given size of sample, by accumulating the information from successive samples.

The application of quality control theory has been simplified in actual practice by the development of tables of constants which permit the technician to use sample-ranges in the short-cut calculation of control limits. Any plotted points falling outside these limits indicate a significant change in the production process, since the likelihood of such an occurrence purely by chance is less than 1:1,000.

Statistical quality control can provide an excellent criterion of the effectiveness of inspection work. Further, it can provide a means of accurately determining whether more or less inspection should be applied to maintain product quality, and *when* and *where* corrective action is needed. A complete discussion of statistical quality control and its application to manufacturing operations is beyond the scope of this text, and the reader is referred to the excellent books available on this subject.[2]

GRAPHIC RECORDS

Even though statistical-quality control may not be used, there is still need for inspection statistics—and graphic analysis—to provide continuous indication of the quality levels maintained in the manufacturing departments and to locate points requiring attention to raise quality to required values.

Management is naturally interested in the cost of inspection operations, as is indicated by the relationship of Inspection per-

[1] From an address entitled "Statistical Quality Control," presented before the Sacramento Statistical Association, Sacramento, Calif., on Mar. 18, 1948.

[2] Bethel, Atwater, *et al.*, "Industrial Organization and Methods," pp. 408–410, McGraw-Hill Book Company, Inc., New York, 1945; Grant, E. L., "Statistical Quality Control," McGraw-Hill Book Company, Inc., New York, 1946; "Guide for Quality Control and Control Chart Method of Analyzing Data," ASA Z1.1 and Z1.2, American Standards Association, New York, 1941.

sonnel values to total employment, and by the amount of work accomplished by each inspector. This can be depicted through periodic extension of a chart showing total inspection labor and inspection employees by major job classifications. A graph of this nature should also show the total company direct-labor employment, to depict the relationship between inspectors and direct-labor factory workers.

Inspection efficiency can be graphically illustrated by plotting quantity of items examined per Inspection man-hour. To be truly significant, a graph of this nature should show separate curves for each major phase of inspection work, such as those for sheet metal, machine shop, bench assembly, and the like. It is admitted that this type of presentation is somewhat ambiguous, as the nature of the items inspected may vary from day to day; but it is a reasonably satisfactory method of judging *comparative* efficiency. In cases where the weight of each item is known, it may be possible to plot weight per hour, but even this will not provide a true representation, for weight is not always a fair evaluation of the complexity of an item.

Scrap is one of the most serious problems in a manufacturing plant, as the number of scrapped items often means the difference between profit or loss. A graph extended daily to show losses in scrapped items is of value to both Inspection and Factory Management. Such a chart should show the total scrap and the amount resulting from each of the major causes: poor workmanship, defective tooling, improper manufacturing methods, engineering error, and customer-requested changes. This type of information is most useful to management when presented in the form of a group of graphs showing totals for the factory and separate graphs for major manufacturing operations or departments.

Similar charts should be prepared to depict the daily quantities of items accepted on first inspection, requiring rework, and rejected for salvage action. An additional chart should reflect the salvage committee's action on rejected items, showing total rejections and quantities repaired, accepted as deviations, and the like.

Tool-inspection activities can be presented as a family of

curves showing the number of production tools, precision tools, and perishable tools inspected. The quantity of tool reworks and rejections should also be indicated, as well as the number of man-hours expended on tool inspection.

Standard repairs and minor discrepancies per end item can also be graphically shown, to provide an indication of final-assembly workmanship. Other special graphs or statistical tabulations may be found desirable to cover special conditions encountered with some end items, but those described herein will provide both the chief inspector and the company top management with an over-all picture of inspection operations and factory quality levels.

CHAPTER 7
EQUIPMENT

Inspection equipment in the form of accurate measuring apparatus and gages was originated in the United States by Eli Whitney in 1798. Since that time the demand for accurate manufacturing and for interchangeability of manufactured parts has created a multitude of increasingly accurate measuring equipment. A majority of the improvements in equipment for quality control have been made during the past 100 years. Development of equipment to insure accurate duplication of dimensions began with the invention in France of the micrometer by M. Jean Palmer in 1848. It was introduced in this country in 1877 by J. R. Brown and L. Sharpe.

Without accurate measuring equipment, inspection would be largely a matter of judgment. Years might be required for an inspector to gain sufficient experience to make him able accurately to accomplish examinations that can now be taught to a new employee in a few hours. Not only would the experience requirements for an inspector be unreasonably high, in the absence of modern inspection equipment, but the time required for inspection operations would be prohibitive.

The accuracy and efficiency of an inspection department are directly proportional to the quality and quantity of available inspection equipment. The variety of equipment made available for inspection purposes must, however, not be carried to unreasonable extremes. Only the equipment necessary to maintain the required quality and to maintain minimum inspection costs should be provided. In other words, the minimum equipment for an inspection department is controlled by the accuracy and variety of inspection operations required. Equipment beyond

this minimum should be added only when its usage will reduce inspection costs by a significant amount.

For instance, a plant where routine production involved grinding cylindrical parts to a diametral tolerance [1] of 0.0005 in. would find the use of several ultraprecision micrometers (such as the Pratt & Whitney Supermicrometer or Sheffield Electrochek) economical for production inspection. It is admitted that a highly experienced inspector, using a hand micrometer equipped with a vernier *could* do a reasonably satisfactory job of checking this close-tolerance diameter, but at a much higher unit labor cost and with considerably more possibility of excessive rejections during assembly operations.

On the other hand, when the smallest tolerance on a dimension is 0.002 in., there is little need for measuring instruments more precise than hand micrometers or dial-indicator gages. A limited quantity of precision measuring equipment may, however, be required for gage and instrument inspection, even in shops where production tolerances are fairly large.

In general, the degree of precision required for inspection equipment is directly related to the dimensional tolerances that must be maintained on production parts. The degree to which it will be economical to provide specialized, single-purpose inspection equipment is a function of the production rate. If hundreds of a precision part are produced each day, and if these require 100 per cent dimensional inspection, then the expense of semiautomatic or automatic multiple-dimension inspection equipment may be desirable, on the basis that the reduction in unit inspection labor will justify the cost of special equipment.

CLASSES OF EQUIPMENT

Inspection equipment can be grouped into three broad classifications: (1) measuring instruments, (2) gages, and (3) testing equipment. Each of these classifications may be further subdivided into functional groups of related equipment.

[1] The *tolerance* is the sum of the limits on the basic dimension. Thus, a tolerance of 0.0005 in. may represent limits of +0.0000 and −0.0005, +0.0005 and −0.0000, ±0.00025, or other plus and minus limits, totaling 0.0005 in. This may also be expressed as "the tolerance is the difference of the minimum and maximum dimensions." Thus, the dimension 1.2500—1.2505 has a tolerance of 0.0005 in.

Measuring Instruments

Measuring instruments are devices for determining the true size of any dimension within the capacity of the equipment. Included in this classification are linear scales, vernier calipers, micrometers, and precision measuring machines. For the sake of convenience, surface-finish analyzers and transits may also be included in this group, for these instruments perform a measuring function. Measuring instruments find their greatest inspection application in low-volume production, where it is desirable to check a variety of dimensions with a minimum of inspection equipment, and in toolmaking, where the problem is basically one of accurately transferring dimensions from a standard to a tool or production gage.

Gages

Gages are devices for determining whether a particular dimension is within its assigned tolerance. Included in this classification are plain and threaded plug and ring gages, snap gages, and blade gages (see Figs. 7:1 and 7:2). These can be considered as single-purpose gages, being designed to check a single dimension or at best being provided with a very limited adjustment range.

The gages shown in Figs. 7:1 and 7:2, in combination with standard forms of measuring instruments, will permit checking a majority of dimensions and are usually satisfactory for low-production operations. When the production tempo increases, requiring rapid, accurate inspection by comparatively inexperienced personnel, different gaging equipment becomes necessary, to reduce unit inspection labor and to minimize errors.

Efficient precision inspection of high-production operations often requires the use of one or more forms of *comparator gages* for rapid checking of diametral, linear, and contour dimensions. These may be in the form of either limit or indicating comparators. Limit comparators determine whether or not the dimension being checked is within tolerance and, if not, which limit has been violated. They do not indicate the value of the dimension measured. Indicating comparators do evaluate the measurement.

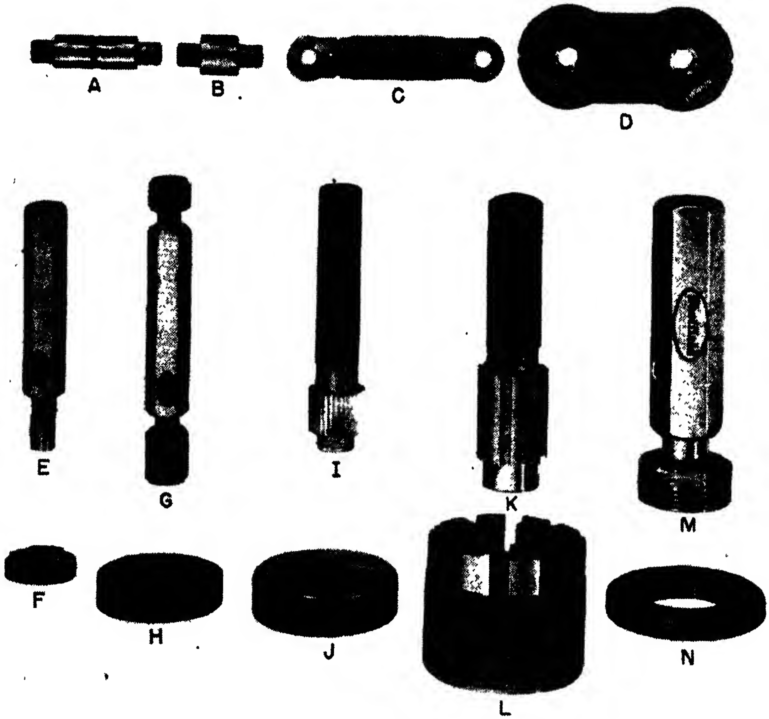


FIG. 7:1. Standard forms of single-purpose gages. *A* and *B*, master disks for setting gages. *C*, go and not-go blade gages for checking slot widths, such as Woodruff key seats. *D*, go and not-go ring gages for external thread. *E* and *F*, plug and ring gages for precision pipethread taper. *G* and *H*, go and not-go plug, and go ring gages for straight thread. *I* and *J*, go plug and ring gages for serration. *K* and *L*, go plug and ring gages for spline. *M* and *N*, plug and ring gages for pipe thread. (*Courtesy of The Sheffield Corporation.*)

Electric, mechanical, and optical comparators are in use. Typical forms of each of these are described in Chap. 9. Many forms of comparators are adjustable over a comparatively wide range, being set to the desired basic dimension and limits with gage blocks. Adjustable comparators are particularly useful in medium-production shops, where the cost of special-purpose inspection equipment would be prohibitive.

Another useful form of comparator is the *air gage*. This depends for its indication on pressure or flow changes which result from air escaping between the surface that is being

FIG. 7:2. Conventional forms of snap gages. All except one are of the standard *go* and *not-go* construction, while the third gage in the upper row is provided with a dial indicator to show actual variation from the basic dimension. (*Courtesy of The Sheffield Corporation.*)

checked and an accurately designed sleeve or snap, with the indication appearing on a pressure or flow gage calibrated to evaluate the measurement. These instruments, which provide a very rapid and highly accurate method of checking internal and external diameters, are particularly useful in checking for taper and out-of-round conditions in long bores. However, expensive spindles and snaps are required for each dimension measured, and this form of gage should be considered only for high-production inspection.

FIG. 7:3. Air gage having gaging spindle integral with gage assembly. Minimum- and maximum-limit checking rings in foreground. (*Courtesy of The Sheffield Corporation.*)

Another important gage is the *multiple gage,* which simultaneously measures a number of critical dimensions. This is a high-production inspection unit, using several electric- or air-gage heads to evaluate simultaneously a number of measurements.

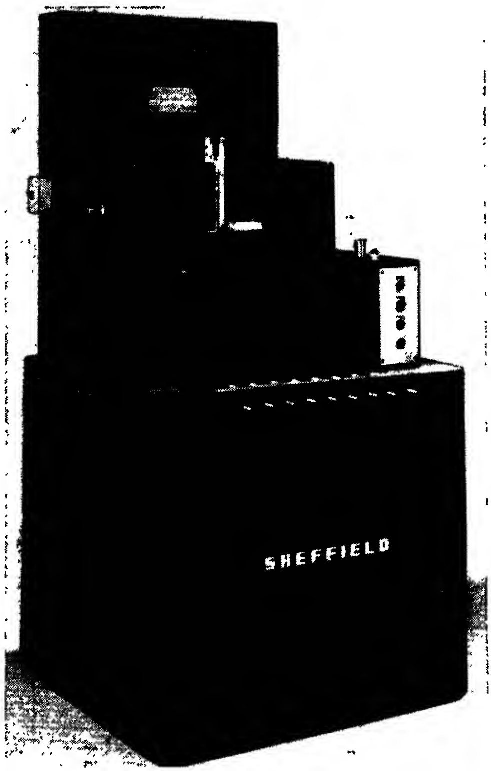


FIG. 7:4. Automatic gaging machine for segregating refrigerating-unit valve plates into 25 classifications. (*Courtesy of The Sheffield Corporation.*)

A master signal light may be used to integrate all the individual measurements, so that the inspector need watch it only to determine if all dimensions are within tolerances. Should the master light indicate a defect, the individual signals provided for each dimension being measured are examined to locate the faulty dimension or dimensions.

Automatic gaging machines are often employed in operations requiring inspection of thousands of identical small items. These

usually involve a machine having a hopper, for receiving the items to be checked, with suitable feeding mechanism to pass the items through electric-gage heads set to limit dimensions. The electric circuits actuate selector mechanism within the gage, to segregate acceptable from rejected items, and may also provide for further segregation of rejected items, in accordance with the nature of their defects.

Other gages used as inspection equipment include *gage blocks,* used as standards for checking and setting other gages; *electronic gages,* used for thickness measurements when the physical nature of the item prevents applying a gage element to both sides of the piece that is being measured; and *optical comparators,* providing high visual magnification of small items, to permit accurate comparison with a standard or actual measurement of critical surfaces.

For the sake of convenience, certain additional equipment related to the checking of dimensional tolerances, such as *sine bars, height gages,* and even *templates,* should be included in the gage classification of inspection equipment.

Test Equipment

Test equipment includes all inspection devices for testing physical and chemical properties. This classification includes hardness testers and magnetic, fluorescent-particle, and X-ray inspection equipment. Apparatus for chemical analysis is also within this group.

A majority of inspection departments have need for hardness-testing equipment, for in almost every manufacturing plant there are requirements for exact material hardness. The tensile strength of steels is a function of hardness, and the hardness-testing machine is commonly used to evaluate the effectiveness of heat-treating operations performed on steels. Several hardness-testing machines are in use, each operating upon a slightly different principle; but the Brinell and Rockwell machines are most frequently encountered.

Both "normal" and "superficial" hardness-testing machines are available. The normal machine is used for testing material that has substantially the same hardness throughout, while the

superficial testing machine is used to determine surface hardness of carburized, nitrided, and other parts having an extremely hard surface "skin" and a comparatively soft core. Other applications of the superficial hardness-testing method are extremely thin parts, such as razor blades and steel springs, or precision surfaces, such as gages that cannot tolerate marring.

The necessity for such special inspection equipment as magnetic, fluorescent-particle, or X-ray apparatus is governed by the volume of items requiring these processes. When the volume is small, it is usually more economical to subcontract this special inspection to a reputable firm specializing in such work, even though the items must be shipped from the factory to the outside inspection activity and then returned for further processing. When the cost of this outside inspection reaches a point at which it is clearly evident that purchase and operation of the special equipment by the company inspection department will effect a continuing saving, it should be obtained—and not before.

INSPECTOR'S PERSONAL EQUIPMENT

In small inspection departments it is customary for inspectors to supply many of the small tools and measuring instruments that are required for their work. These include such items as scales, vernier calipers, scribes, thickness gages, radius gages, vee blocks, and micrometers. This practice is entirely satisfactory when each inspector's personal tools are carefully recorded upon his beginning employment, checked out upon termination of employment, and periodically inspected for accuracy. See Chap. 15 for additional information on tool control.

Many large organizations consider it desirable to issue company-owned precision tools to all factory personnel on a daily loan basis, and thus to maintain positive control over all measuring equipment and gages in the factory. All loaned precision tools are returned to the tool storerooms at the end of each shift and are checked for accuracy before reissue. In some instances, particularly where an extremely precise product is involved, the company may not allow personal tools of any nature and will supply *all* tools required by factory personnel.

EQUIPMENT FURNISHED BY COMPANY

Normal practice involves the company's supplying *all* gages, precision instruments, and test equipment required for manufacturing and inspection purposes. These are carefully recorded

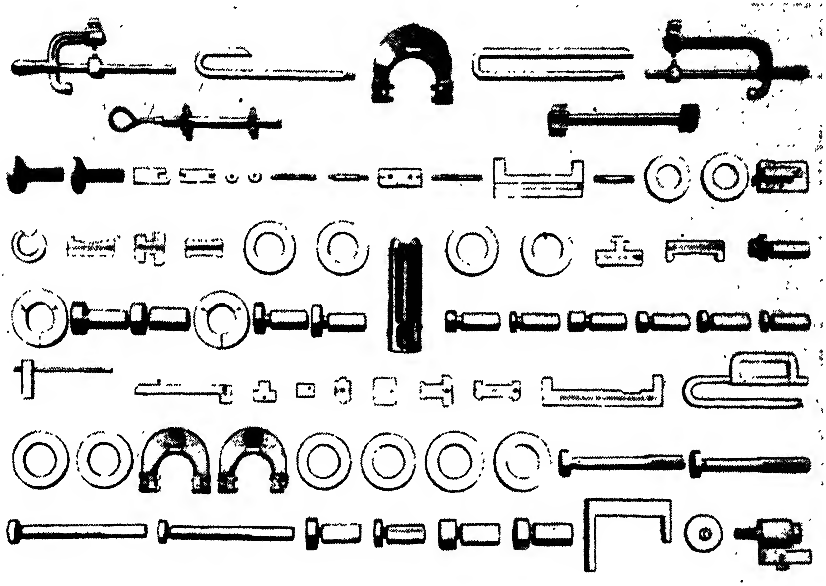


FIG. 7:5. One set of gages used to check 75-mm. shrapnel bodies. This illustrates the variety of gages sometimes required for inspection of high-production precision items. (*Courtesy of The Sheffield Corporation.*)

and are periodically reinspected to insure their accuracy. Use or possession in the factory of personal tools similar to those supplied by the company is strictly prohibited, and this rule may be enforced by periodic toolbox inspections.

Methods for the recording, inspection, and control of company and personal tools, gages, and instruments are outlined in Chap. 15.

TYPICAL INSPECTION EQUIPMENT

Chapters 8, 9, and 10 are devoted to operating principles and constructional details of a variety of typical inspection equipment of American manufacture. Inclusion or omission of the

products of a particular manufacturer should not be construed either as recommendation or as disapproval of individual products.

Comments relative to the respective merits of the equipment described have been avoided. The information given for each is based upon data furnished to the author by manufacturers of inspection equipment. Readers may form their own conclusions regarding the relative merits of the equipment described.

Summarized operating instructions are given for certain of the inspection equipment described in the following chapters. It is not intended that these instructions should be used as guides in operating inspection equipment. Instead, these are offered only to provide a general indication of the procedures and skills required. Detailed instructions to guide inspection personnel actually using precision measuring, gaging, and testing equipment should be obtained from their manufacturers.

CHAPTER 8

MEASURING INSTRUMENTS

Commonly used measuring instruments, such as scales and hand micrometers, are well understood by inspection personnel and are excluded from this discussion. Emphasis is directed to those items which are not universally owned and used by inspectors but which are essential to precision inspection. Among these are the *supermicrometer, standard measuring machine, precision level, contour measuring projector,* and *surface-finish analyzer.*

SUPERMICROMETER

The Pratt & Whitney Supermicrometer is a compact production-measuring instrument, capable of reading directly and accurately to one ten-thousandth of an inch (0.0001 in.) over a range of 9 in. The human error possible with various inspectors reading hand micrometers is largely eliminated, and the use of this type of instrument on precision products will tend greatly to minimize defective items and to reduce manufacturing cost. Use of this instrument or an equivalent is mandatory for accurate gage control.

The Supermicrometer consists essentially of a heavy shaft known as the "barrel," fixed in the micrometer headstock and supporting the movable tailstock. The micrometer headstock reads in ten-thousandths and has a 1-in. spindle travel. Support is provided by a base on the headstock and an adjustable leveling screw at the opposite end of the barrel. An elevating table is provided, sliding along the barrel between head and tailstocks, to position the item that is to be measured. A channel bar may be inserted through head and tailstocks, to support gage blocks that are used to adjust the tailstock for the required range.

The operation of this instrument is free of complications.

With the channel bar in place, the number of 1-in. gage blocks that will produce the required range are inserted between the anvils. The headstock anvil is set to zero and the tailstock brought up until the anvil contacts the gage blocks and its indicator registers on a setting line. The tailstock is then clamped and the indicator is realigned. Following this, the headstock vernier is set to zero. The gage blocks and the channel bar are

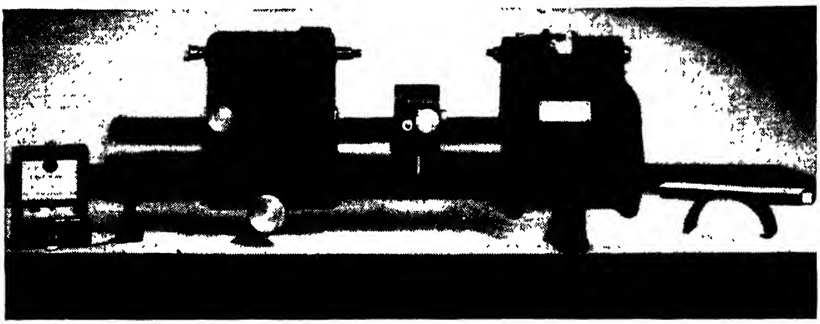


FIG. 8:1. The *Supermicrometer.* (*Courtesy of Pratt & Whitney Division, Niles-Bement-Pond Company.*)

now removed, and the Supermicrometer is ready for use. Any measurement within the range selected can now be made to an accuracy of 0.0001 in., using the 1-in. headstock-spindle travel for the final measurement.

The accuracy of the Supermicrometer can be affected by the skill used in setting up for the required range, and by the gage blocks used. The manufacturer of this instrument recommends that only Pratt & Whitney Standard Inches be used for setting purposes. These are disks made of the same material and to identical quality standards as precision gage blocks, with a 1-in. diameter, accurate to 0.000010 in.

The tailstock contains a pressure device that is in operation when the indicator needle registers on the setting line, to provide an accurate pressure of either 1 or 2½ lb against the object being measured. The 1-lb pressure is used for checking threads finer than 20 per inch by the three-wire method and for general work. The 2½-lb pressure is used for 20 threads per inch and coarser. This greater pressure has been found desirable for

properly centralizing the coarser pitches in the measuring instrument, and the wires are large enough to withstand this pressure without deformation. This constant-pressure feature practically insures that different men will obtain the same measurement to 0.0001 in. on a given item. Either pressure value can be instantly selected by adjustment of a knob at the end of the tailstock.

STANDARD MEASURING MACHINE

When a high accuracy of measurement is required, an instrument such as the Pratt & Whitney Standard Measuring Machine can be used. This provides accurate dimensional evaluation through direct reading of measurements in increments of hundred-thousandths of an inch (0.00001 in.). An instrument of this type can be used as a means of checking gages, tools, and ultraprecision parts, to insure that these products always are correct for size and interchangeability.

This instrument consists essentially of a master bar, a dividing screw and measuring head contained in the headstock, and a tailstock containing a means of controlling measuring pressure—all mounted on a rigid bed incorporating parallel ways to guide measuring head and tailstock. The master bar is graduated at each inch interval, providing a permanently accurate standard for setting. These graduations are extremely fine hairlines, scribed on plugs set in the master bar and visible only through a microscope.

The measuring head includes a microscope, with two hairline graduations used when setting to match a hairline on the master bar, and a precision dividing screw, which subdivides 1 in. The measuring pressure is controlled by an electronic indicating device in the tailstock, registering pressures of 1 to 2½ lb in increments of ½ lb on a sensitive milliammeter, located on the measuring head. Supports and an elevating table, which vary the height of the work above the ways to bring it in proper relation to the measuring anvils, are furnished with the machine.

The operation of the standard measuring machine requires extreme care, to obtain consistently accurate results. While it is not difficult to use, it should never be handled by anyone not

thoroughly familiar with its operation. For greatest precision, it should be handled by the same person at all times. When the machine is not in use for an appreciable time, all accurate steel parts should be coated with white petrolatum as a protection against corrosion.

The first step in preparing the machine for use is adjusting the microscope. This is done by locating the headstock to bring the

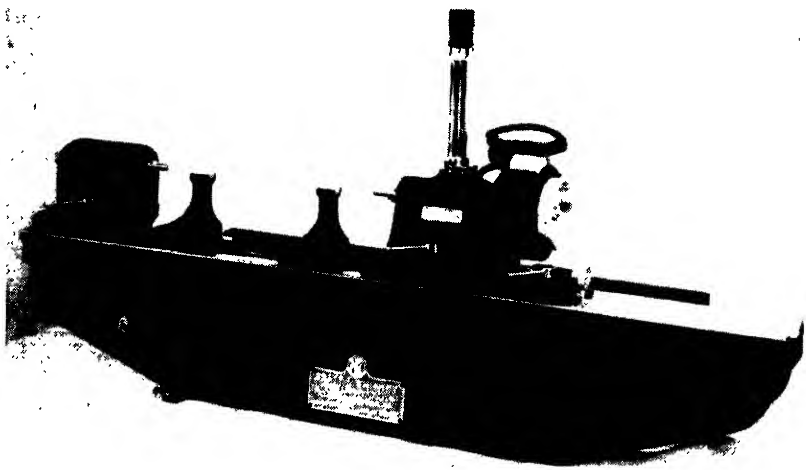


FIG. 8:2. The Standard measuring machine. (*Courtesy of Pratt & Whitney Division, Niles-Bement-Pond Company.*)

microscope approximately over the zero plug in the master bar, and switching on the microscope illuminating lamp. However, the headstock is not tightened on the bed at this time. The microscope is then adjusted until the clear black lines in the head of the microscope are visible.

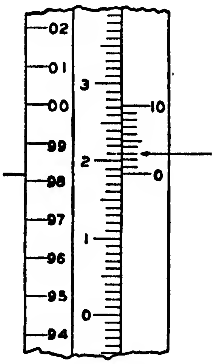
The microscope binding screw is then loosened, and the microscope tube is raised or lowered until another clear black line appears. This line is on the zero plug in the master bar. When this line appears at its best, the binding screw is tightened.

The headstock is now tightened on the bed and final adjustment is made with the fine-pitch screw. This fine-pitch screw is adjusted until the line on the master bar is midway between the lines in the microscope. The headstock is then firmly clamped in place.

The indicating scale handwheel at the end of the headstock is then moved to bring the zero line on the tenths-hundredths scale opposite the witness line.

The tailstock is then carefully moved toward the headstock until their anvils just touch. The tailstock is then tightened and the handwheel turned until the milliammeter reaches the center of its scale. Following this operation, the vernier adjustment is moved to bring the zeros on the vernier and the thousands scale in line.

At this point the adjustments are rechecked, to make certain that the lines in the microscope and on the master bar coincide, that the zero on the thousandths scale is at zero on the vernier, and that the pointer on the milliammeter is at the center of the scale. If all these conditions are correct, the tailstock is in the true zero position and seldom should have to be relocated.



0.98183 in.

FIG. 8:3. Indications of the Standard measuring-machine scales for a value of 0.98183 in. (*Courtesy of Pratt & Whitney Division, Niles-Bement-Pond Company.*)

If it is desired to measure other lengths within the capacity of the machine, the headstock is loosened and moved to the required plug on the master bar. The headstock should be adjusted to this plug, as previously described for zero position.

The indicating dials in the headstock provide for reading the measurement to 0.00001 in. and are actuated by movement of the dividing screw. The dial indications for a measurement of 0.98183 in. are shown in Fig. 8:3. Tenths and hundredths of an inch are indicated on the left-side scale by reading the first two digits coinciding with or below the witness line at the left of the scale. In the example illustrated, the first two digits of the measurement are 9 and 8 or 0.98 in.

The central scale reads from zero to 10 and is divided into four quadrants, each having 100 divisions. One division represents 0.0001 in. Referring to Fig. 8:3, the zero line on the right-side, or vernier, scale lies between 18 and 19 on the thousandth–ten-

thousandth scale. As it is less than 19, this part of the measurement is read as 18. Now by comparing this with the reading on the left-side scale, the value of 0.8918 is obtained.

The vernier scale is calibrated from zero to ten and each division represents 0.00001 in. At the setting shown in the example, the only vernier division line (see arrow) that exactly coincides with any of the adjacent lines on the central scale is 3, and this represents the value of the last digit in the five-place measurement. Thus, the true value of the measurement is 0.98183.

PRECISION LEVEL

The precision level is a sensitive instrument for use in installing and leveling precision machine tools and instruments. The

FIG. 8:4. Leveling a milling-machine table, using a precision level. (*Courtesy of Pratt & Whitney Division, Niles-Bement-Pond Company.*).

frame of the Pratt & Whitney precision level shown in Fig. 8:4 is 15 in. long and is provided with insulating handgrips, to minimize temperature change while handling.

Each division on the level scale indicates a variation from the

horizontal of 0.0005 in. in 1 ft. The vial adjustment provides for self-checking, a feature obtainable in high-quality precision levels.

CONTOUR MEASURING PROJECTOR

The Bausch & Lomb contour measuring projector may appear upon superficial examination to be a comparator, properly belong-

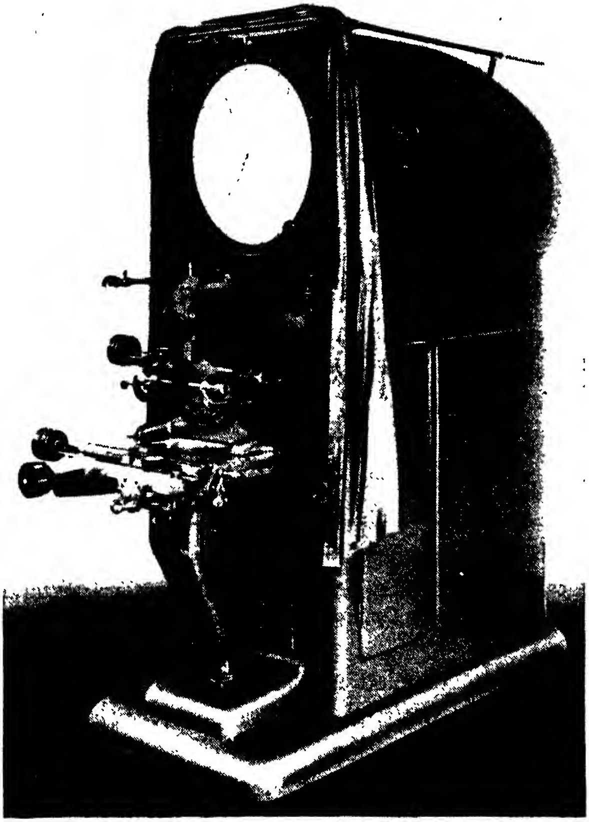


FIG. 8:5. Bausch & Lomb contour-measuring projector, equipped with protractor screen and screw-thread measuring attachment with work in position. (*Courtesy of Bausch & Lomb Optical Company.*)

ing in the gage classification. It is true that this instrument will perform all the functions of a conventional optical comparator, but it is also equipped with micrometer dividing screws, pro-

viding direct reading measurements through a combination of mechanical and optical means. On this basis, it is classified as a measuring instrument, rather than a gage.

This instrument uses the principles of optical projection to

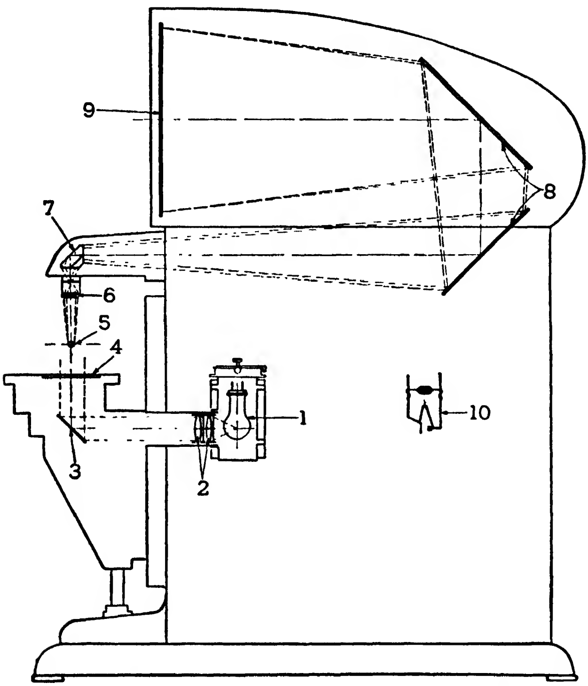


FIG. 8:6. Optical system of the Bausch & Lomb contour-measuring projector. (*Courtesy of Bausch & Lomb Optical Company.*)

form an extremely precise shadow image of an object under magnification. This method enables many measurements that may not otherwise be practicable.

The Bausch & Lomb contour measuring projector essentially consists of an optical system (see Fig. 8:6) involving a light source, condenser lenses, and a mirror to direct a concentrated light beam vertically upward through a glass plate in the work-table, past the object being examined, and into the projection-lens assembly. The light beam, now carrying the outline image of the object, is focused by the projection lenses upon a prism, which directs the vertical beam horizontally aftward to an in-

clined mirror. This mirror directs the image beam vertically upward to another inclined mirror, which projects the beam forward to register on the aft surface of a translucent screen located directly above the worktable and clearly visible to the

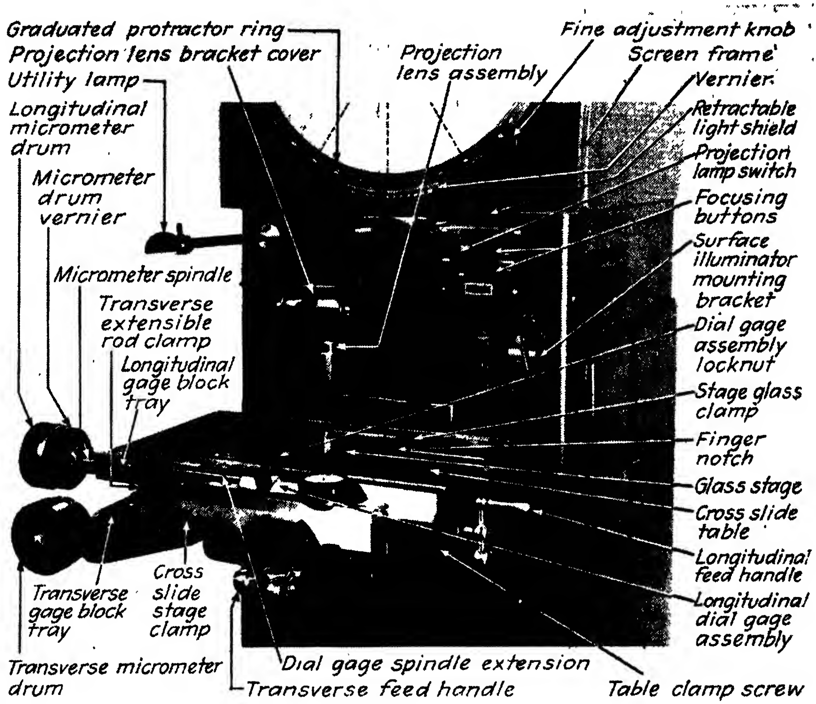


FIG. 8:7. Principal components and controls of the B & L contour-measuring machine. (*Courtesy of Bausch & Lomb Optical Company.*)

operator. Vertical adjustment is provided for the worktable, to position the object under examination.

Angle measurements may be read directly through the medium of index lines, protractor scale, and vernier, when the protractor screen (see Fig. 8:5) is used. Linear measurements can be made either by scaling the image on the screen or, when precise measurements are required, by making use of the longitudinal and transverse motions of the cross-slide worktable controlled by micrometer dividing screws (see Fig. 8:7). When these accessories are installed, one edge of the image is brought to coincide with a reference line on the screen, and the micrometer drum and

dial indicator for the required direction of measurement are set to zero, with their anvils touching. The table is then moved until the opposite edge of the image comes into coincidence with the reference line, the micrometer is advanced until the anvils again touch and the dial indicator reads zero. The measurement is then read directly from the micrometer drum to the nearest ten-thousandths of an inch.

Longitudinal dimensions up to 6 in. and transverse dimensions up to 4 in. may be measured by this means, although the dividing screws are limited to a travel of 1 in. Gage blocks are used between the micrometer and dial-indicator anvils for measurements in excess of 1 in.

Detail instructions for the operation of the Bausch & Lomb contour measuring machine are beyond the scope of this dis-

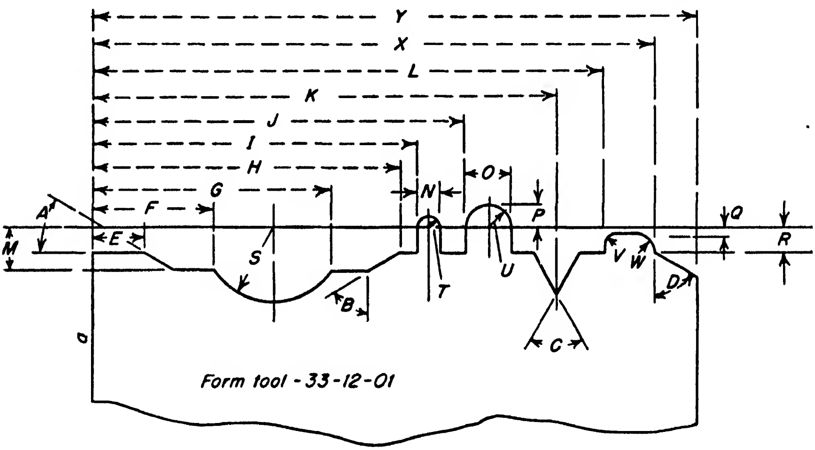


FIG. 8:8. Typical dimensions feasible of measurement with the B & L contour-measuring projector. (*Courtesy of Bausch & Lomb Optical Company.*)

cussion, but a general indication is provided in a description[1] of the procedure followed in measuring the form tool shown in Fig. 8:8.

Proceed as follows: Set the protractor screen scale at zero.

Place the form tool on the glass stage and focus the cutting edge

[1] From "The Bausch & Lomb Contour Measuring Projector," Catalogue D-27, 3, IV-46, Bausch & Lomb Optical Company, Rochester, N. Y.

sharply. Locate the tool so that the working edge (*a*) coincides with the vertical centerline on the screen. With the right and left micrometer set at zero, move the dial indicator along the "T" slot to make contact with the micrometer spindle, so as to rotate the indicator about one half turn. Clamp the assembly in this position and set the dial to read zero.

Check the setting by rotating the micrometer drum to assure a simultaneous zero reading of both micrometer and dial gage.

Now move the table *to the left,* until the image of the point of intersection of *E* and angle *A* coincides with the vertical reference line. Rotate the micrometer drum to bring the indicator up to zero. The micrometer reading will be the dimension *E*. Repeat for *F, G, H, I, J, K, L,* and *Y,* using both size blocks and micrometer, if the dimensions exceed 1 in.

To measure the angle *A,* rotate the screen counterclockwise and move the slides until the vertical reference line coincides with the image of the angular edge, and take the reading directly from the graduated screen ring and vernier on the left side of zero.

The angle *B* is measured by using the same vertical reference line, rotating the screen clockwise, and moving the slides to bring the two lines into coincidence. Take the reading directly from the screen ring and vernier on the right side of zero.

Follow these procedures to measure angles *C* and *D*. All angles can be measured to a least reading of one minute of arc (1′).

Radii *S, T, U, V,* and *W* can be checked to master outlines, drawn on translucent material to the proper magnification. If a radius is unknown, a tracing of the magnified image can be made on translucent paper and fastened to the screen by Scotch tape. The radius on the sketch can then be measured with ease and accuracy.

Now check the vertical dimensions *M, P, Q, R,* and *S*. With the screen set at zero, bring the radius *U* tangent to the horizontal reference line. Set the back-and-front micrometer drum at zero. Loosen the clamp screw on the extensible rod, underneath the table at the left end, and hold the outer end firmly against the micrometer spindle. Extend the opposite end to get about one-half turn on the dial indicator. Tighten the clamp screw.

Set the dial at zero and, after assuring a simultaneous zero reading of both micrometer and indicator gage, by rotation of the micrometer drum, proceed with the measurements, as with the above right and left check.

SURFACE-FINISH ANALYSIS

Even the most smooth-appearing machined surfaces look rough when viewed through sufficient magnification. Appearance alone is not a reliable criterion of surface finish, as a surface that seems to be quite smooth may appear as rough as that shown in Fig. 8:9 when inspected under even moderate magnification. Further, two equally experienced inspectors may have widely divergent opinions of the quality of the surface finish on a given part when they depend solely upon visual examination of the item.

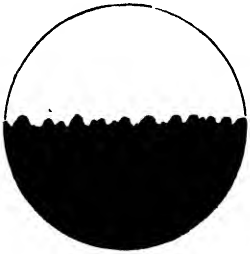


FIG. 8:9. Cross-section magnification of a ground surface showing furrows and intervening ridges. (*Courtesy of The Sheffield Corporation.*)

Thus, it becomes evident that there is need for an adequate standardized system of designating surface finishes and for a device to measure accurately the actual finish on items requiring a certain minimum smoothness. The requirement for minimum smoothness of certain surfaces is critical with many precision items. For instance, the wearing surfaces of hydraulic actuating cylinder barrels and piston rods must be machined to a mirror-like finish, to avoid damage to the sealing rings.

THE RMS MICROINCH SURFACE-FINISH SYSTEM

When precision surface finishes are important, the time-honored system of "spelling out" the finish required as *smooth-machine finish, grind, lap,* and the like becomes unsatisfactory, for these notations merely designate machining operations and do not establish a quality standard that can be indisputably measured. Attempts to augment these designations by supplying sample parts to operators and inspectors involved in maintaining surface finish have proved equally unsatisfactory. Not only is it difficult to duplicate a number of samples of identical surface finish in the absence of a surface-finish measuring instrument, but the quality of work still remains a matter of opinion. There is no guarantee that shop foreman and inspector will

agree as to whether the work in question is equivalent to the finish sample.

There has been considerable progress in the development of instruments to measure surface roughness, but these have been of dubious value in the absence of accepted standards to implement their use. The problem of a satisfactory standard was solved by the American Standards Association, which in 1947 released ASA standard B46.1, "Surface Roughness, Waviness, and Lay." This represented the culmination of nearly 15 years' study of the problem and established a system of microinch (millionths of an inch) evaluations of surface irregularities. The roughness of a given surface is expressed as a numerical value (*i.e.*, 100, 40, 20, 5), representing the root-mean-square (rms)

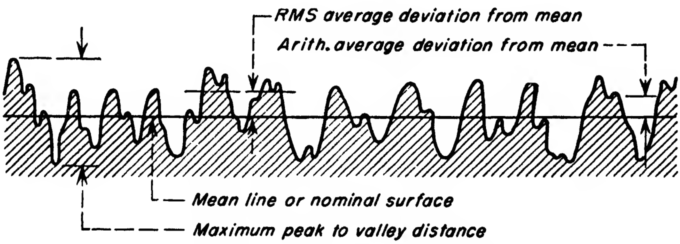


FIG. 8:10. Rms value and arithmetical average of surface variations. (*Courtesy of Surface Checking Gage Company.*)

microinch measurement of the variations of the actual surface from a hypothetical nominal or mean surface line,[2] as shown in Fig. 8:10.

The root-mean-square (*i.e.*, the square root of the average of the squares of a large quantity of individual surface variations) and arithmetical average values for microinch surface variations normally correspond closely, and from a practical viewpoint either value could have been used. However, the standardizing groups who developed the microinch finish system chose the rms system and, from the consideration of using the system, the mathematics involved in its creation are of little consequence.

[2] The material contained herein on the rms microinch system of finish designated is based upon data contained in James A. Broadston's "Control of Surface Quality," Surface Checking Gage Company, Hollywood 28, Calif., 1944.

Rms Microinch Symbol

Various symbols based upon a check mark have been used to designate rms microinch finish requirements, but it remained for North American Aviation, Inc., to devise a truly distinctive symbol, one that would be sufficiently conspicuous to insure immediate recognition on drawings. This one, shown in Fig. 8:11, provides not only for the maximum permissible surface roughness but also for designation of *lay* and *waviness* requirements. *In a majority of cases, the symbol will be found with only a roughness designation, as cases requiring precise lay and waviness are the exception.*

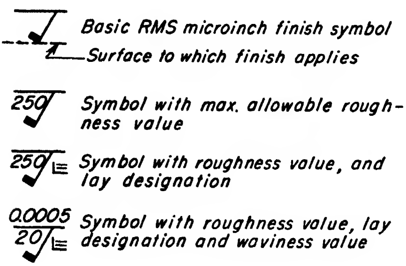


FIG. 8:11. Rms microinch surface-roughness symbol.

Lay, in reference to surface finish, is the direction of the predominant toolmarks, grain, or pattern of surface roughness. All surface-roughness measurements are normally taken across the lay, as this gives the best comparative value and the highest readings on a tracer-point surface-finish analyzer. Turned, milled, and ground surfaces have definite lays, while lapped or superfinished surfaces have not; they are classed as multidirection lay. Surface-finish measurements may be made in any direction on these surfaces.

Waviness is that deviation from a nominal surface which ordinarily takes the form of smoothly rounded waves. This condition results from deflection of the machining tool, through vibration of the machine or as the result of similar causes of consistent machining inaccuracies. The waviness is usually of greater magnitude than the roughness value and can be specified as a decimal-fraction inch value, establishing a maximum allowable peak-to-valley height, as measured by a sensitive dial indicator having a 1/16-in. ball contact. It is doubtful whether waviness is as important as was once thought, and in most cases a more satisfactory method of designating the "flatness" of a machined

surface is use of a percentage bluing note. This indicates that the surface shall show a certain per cent contact when checked with Prussian blue and a surface plate or some similar device.

The actual surface-roughness numerical values established for the rms microinch system range from 1 to 63,000, with 1 repre-

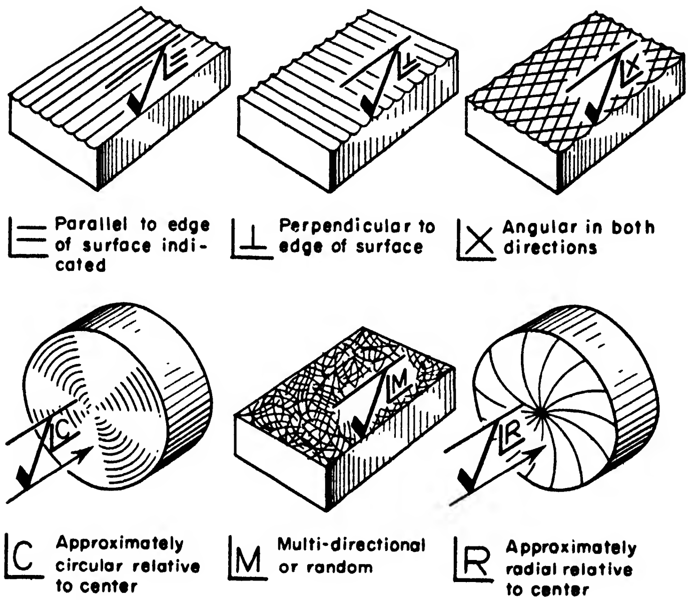


FIG. 8:12. Lay of machined surfaces and their designations in the Rms microinch symbol. (*Courtesy of Surface Checking Gage Company.*)

senting the smoothest finish considered practicable of attainment. Obviously there is little need for varying finish requirements in increments of one number, and the real need is for reasonable values representing practicable, usable graduations of surface finish. Unfortunately, a uniform standardization of practicable values has not been reached by industry, although the need for surface-finish values is practically the same throughout all manufacturing. A practical system has been developed by the National Aircraft Standards Committee, which provides for nine preferred finish numbers. This system, which is widely used by producers of aircraft and components, appears entirely satisfactory for even the most precise items. The preferred num-

bers established by the NAS standard, ranging from very rough to extremely smooth, are 500, 250, 100, 40, 20, 10, 5, 2, 1.

Another system of preferred numbers, established by the Society of Automotive Engineers, provides for the following,

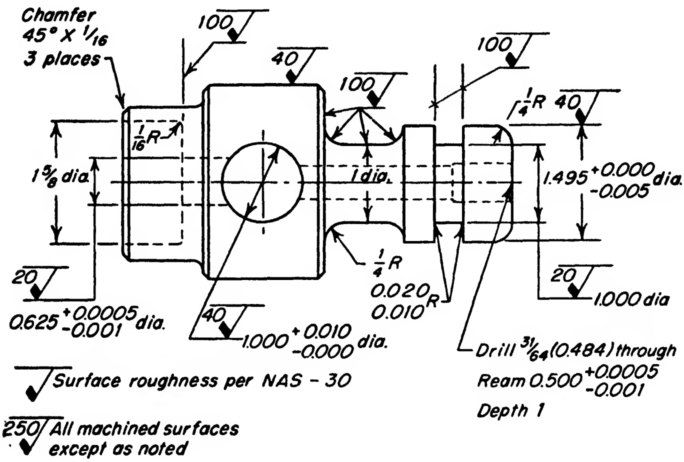


FIG. 8:13. Use of rms microinch symbols to show finish requirements on cylindrical part requiring machining all over. (*Courtesy of Surface Checking Gage Company.*)

with first preference given to the underscored numbers: 500, 400, 320, 250, 200, 160, 130, 100, 80, 60, 50, 40, 32, 25, 20, 16, 13, 10, 8, 6, 5, 4, 3, 2, 1.

The preferred numbers of the American Standards Association for indicating rms microinch surface roughness are 1, 2, 4, 8, 16, 32, 63, 250, 1,000, 4,000, 16,000 and 63,000.

The NAS system of nine preferred numbers represents a practicable scheme, with sufficient variations in finish between values to permit intelligent description of the nature of each, and is considered by many to be the most satisfactory arrangement. The discussion of the nature of designated standard finishes given herein is limited to the values established by the National Aircraft Standards Committee.

NAS Preferred Finish Numbers

The 500 microinch rms surface is a very rough low-grade machine finish, comparable to that produced with heavy cuts

and course feeds in milling, turning, shaping, and boring, as well as from rough filing and disk grinding. The unmachined surfaces of many forgings and castings are within this value.

The 250 microinch rms surface compares with the original *f*–5 classification and shows toolmarks resulting from a rapid feed, producing a medium machine finish. This surface may also be produced by a very coarse surface grind, a smooth file, a smooth disk grind, a coarse emery buff, and similar operations. Scratches caused by chips are not a valid cause for rejection unless they are present in excessive size and numbers.

The 100 microinch rms surface is a smooth machine finish, approximately equal to the original *f*–3 classification. It is the result of high-grade machine work produced by relatively high speeds, fine feeds, light cuts, and sharp cutting tools. All standard machining methods can produce this finish under proper conditions, including coarse surface and cylindrical grinding, and smooth hand filing.

The 40 microinch rms surface corresponds to a very fine machine finish, a carbide or diamond bore, a medium surface or cylindrical grind, a rough emery buff, ream, burnish, and similar operations. This finish, in the case of turned parts, is usually the result of removing fine toolmarks by subsequent handwork with fine emery cloth. On flat parts, an equivalent surface may be produced by a power sanding machine and fine-grit belt. Use of this surface finish increases shop costs, as its consistent achievement demands special care.

The 20 microinch rms surface is produced by fine cylindrical grind, very smooth ream, fine surface grind, smooth emery buff, coarse hone, or a coarse lap. This finish is used only where smoothness is of primary importance.

The 10 microinch surface is produced by the finest cylindrical grinding, honing, lapping, or buffing. The appearance of surfaces of 10 rms or finer is not a dependable means of judging quality, as these finishes may be either bright or dull, depending upon the machining method. Accurate comparison of fine finishes requires either "feel" or the use of roughness-measuring instruments.

The 5 microinch rms surface is normally produced by honing, lapping, superfinishing, very fine buffing, or bright polishing.

This finish is normally used only for applications where lubrication is not dependable and packings and rings must slide across the direction of the surface grain.

The 2 and 1 microinch surfaces are included in the NAS standard classifications, but manufacturing experience has established little need for these incredibly fine finishes. In Fig. 8:14, the

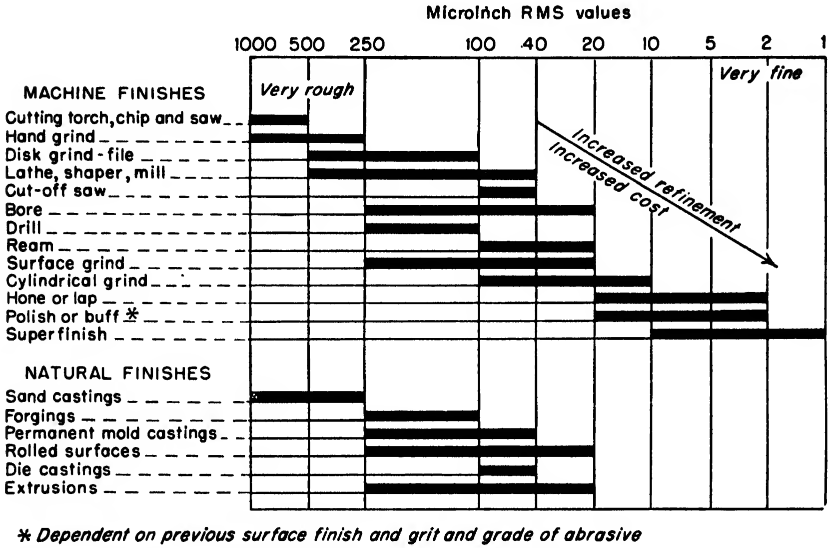


FIG. 8:14. Normal surface-roughness values. (*Courtesy of Surface Checking Gage Company.*)

chart describes the normal finishes obtained with raw-stock materials and standard machining operations. This can be used by the inspector in determining the finish to be expected from a particular operation.

SURFACE-FINISH MEASUREMENT INSTRUMENTATION

Several types of surface-finish measuring instruments are available, but it is doubtful whether any one of the present devices is entirely satisfactory. Those providing the most accurate analysis are often impractical for shop or inspection usage. All are delicate, precision instruments requiring considerable skill on the part of the operator, and the very nature of the basic measuring problem can lead to endless difficulties.

The complexity of the problem can be visualized by examina-

tion of the views shown in Fig. 8:15. The view at the left is a lapped surface, while that at the right is a ground surface. It is entirely possible for each to have identical surface-roughness values, in the neighborhood of 10 microinch rms, although the actual surfaces are obviously quite different. The lapped surface is free from clearly defined toolmarks, while the ground specimen has a multitude of approximately parallel scratches of slight

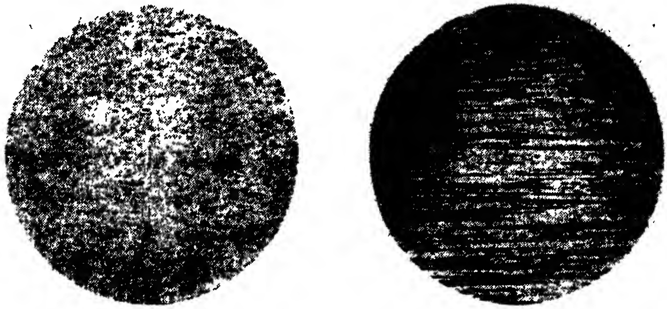


Fig. 8:15. Comparison of lapped and ground surfaces. (*Courtesy of The Sheffield Corporation.*)

depth. Yet in each case the measuring instrument should show approximately the same surface-roughness indication.

A majority of practicable surface-finish analyzers available at present utilize the tracer-point principle, wherein a special needle attached to a piezoelectric crystal (similar to an electric phonograph pickup) is traced over the surface to be measured. The resultant electric impulses are amplified and utilized to actuate meters or recorders.

The *Brush Surface Analyzer* consists of an adjustable pickup head, an amplifier, and a direct-inking oscillograph. This instrument provides a record of surface roughness through tracing an ink line upon a moving paper tape, the traced line being an approximate representation of the surface traveled by the pickup point. Calibration standards are provided with this instrument, for checking the accuracy of its operation.

The Brush analyzer tape provides a permanent record of surface roughness as interpreted by the analyzer. However, the curve is actually an exaggeration of the real profile, because of

extreme magnification in the vertical direction. The irregularities indicated by the Brush record, even after correction for vertical magnification, are not the true shape; the record curve is an interpretation made from the motion of the tracer point, including the distortions resulting from the mechanical and electrical characteristics of the pickup, amplifier, and oscillograph. This instrument does, however, give more information regarding the actual condition of the surface than can be obtained from the simple roughness-number indication shown by meter-type analyzers.

The *Profilometer* is a surface-finish analyzer giving direct indication of the magnitude of surface irregularities. As the tracer unit, containing a diamond-point pickup, is slowly moved back and forth over the surface being measured, the electrical impulses created within the unit are amplified to actuate a meter calibrated in microinches. The meter needle oscillates rapidly during the reading, but damping action inherent within the meter tends to average the variable impulses. The roughness value is usually taken as being the maximum sustained reading. Occasional sharp meter deflections are ignored.

This instrument provides an excellent method for making spot-check comparisons of finely finished surfaces. The versatility of this instrument and the ease with which it can be operated make it particularly valuable for rapid inspection checks.

SURFACE-ROUGHNESS COMPARISON

It is obvious that Brush analyzers, Profilometers, or other forms of precision surface-finish analyzers could not be provided throughout a manufacturing plant. It is apparent that the only practical solution is providing accurate surface-finish samples to engineers, tool designers, machinists, and inspectors.

The use of comparison samples has been accepted as an accurate method of evaluating surface-finish roughness. While the appearance of a sample is not a satisfactory criterion of its roughness, the difference in roughness of two surfaces becomes immediately apparent upon the scraping of a fingernail over the surfaces. In addition to determining obvious differences, the fingernail, or "feel," comparison is valid in determining minute

variations in surface roughness. It has been clearly demonstrated that, through feel, even inexperienced personnel can make roughness comparisons both rapidly and accurately.

The problem, then, in cases where accurate control must be maintained over surface finish, is one of providing precisely accurate surface-roughness specimens to all parties involved with the establishment and control of surface quality. Accurate commercial standard finish specimens are available, such as those developed by the Norton Company, University Machine Co., United States Rubber Co., and General Electric Company. Unfortunately, many of these are too expensive to permit supplying sets of specimens to all parties concerned with surface-finish control. Yet, it is this widespread distribution of finish specimens which is absolutely essential in any comprehensive and efficient program of surface-roughness control.

Surf-chek Roughness Standards

One inexpensive roughness standard is the *Surf-chek*, produced in the form of comparison gages made of a phenol-formaldehyde molding compound. The basic comparison standard provided in this system, shown in Fig. 8:16, is a 4⅝- by 7⅛-in.

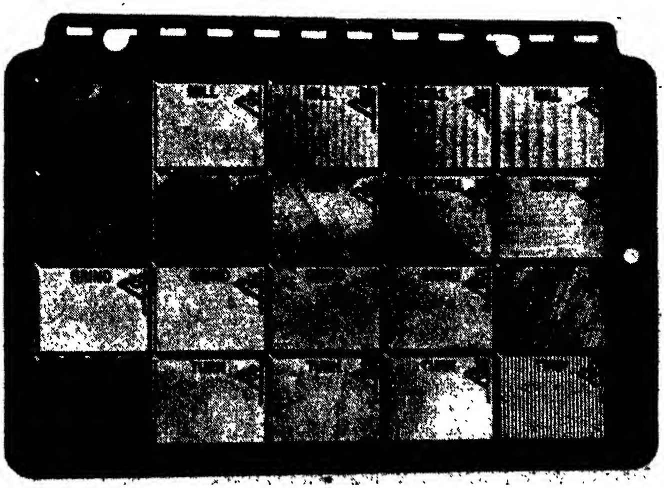


Fig. 8:16. Surf-chek roughness standard. (*Courtesy of Surface Checking Gage Company.*)

plaque containing 20 surfaces of varying degrees of roughness conforming to NAS preferred values. This plaque provides replicas of the following surfaces, produced by the designated machining operations: 500-mill, 500-turn, 250-mill; 250-endmill, 250-grind, 250-turn; 100-mill, 100-endmill, 100-grind, 100-turn; 40-mill, 40-grind, 40-turn; 20-grind, 20-hone; 10-grind, 10-hone, 10-lap; 5-lap, and 5-polish.

Smaller Surf-chek plaques provide groups of specimens for particular machine operations in either NAS, SAE, or ASA preferred surface-finish numbers. Surf-chek specimens of another type are disks similar to poker chips. Each provides a standard for one designated finish number. These can be combined into sets by being attached to a key chain and can be issued to machinists and inspectors like any other tool.

ROUGHNESS COMPARISON IN INSPECTION

When the nature of the product requires accurate control of surface finish, this can best be accomplished by providing adequate finish standards to both shop and inspection personnel. These can be used for comparison purposes in evaluating the actual finish of machined parts and should serve a majority of inspection purposes. In addition, the inspection department should have an accurate surface-finish analyzer, to be used in checking dubious cases. The analyzer should be kept in the gage and instrument section of Inspection, and its usage should be restricted to designated inspectors, known to be proficient in using it.

In all surface-finish inspections there are two possible limits. Either a range (*i.e.*, 40 to 100), or a maximum roughness will be specified. The inspector is concerned primarily with determining that the finish is either within the range or below the maximum.

James A. Broadston, writing on inspection control of surface quality, says: [3]

Production control and floor inspection usually involve all three methods of comparison: some visual inspection, comparison by feel

[3] "Control of Surface Quality," 2d ed., Surface Checking Gage Company, Hollywood 28, Calif., 1944.

for all normal conditions, and instrument comparison where very close control is necessary.

When a job has been set up, the first few pieces are normally compared by feel (or instrument) with standard surface-finish specimens conforming to the finish required. On the basis of this initial control,

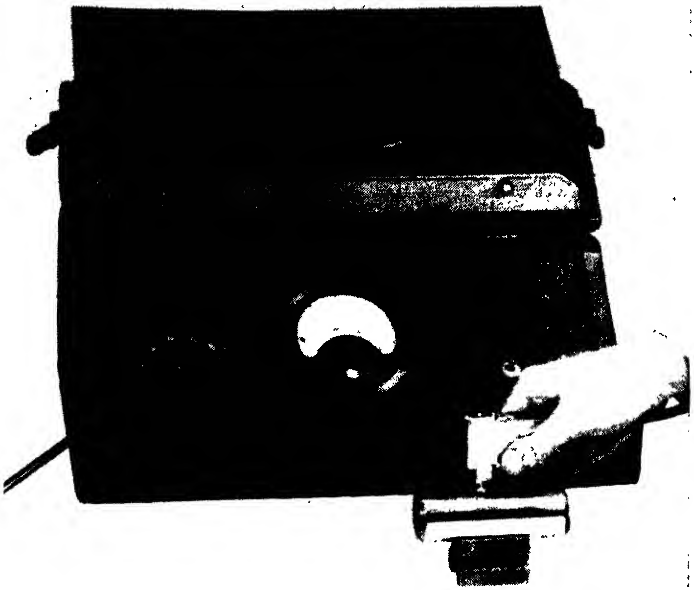


FIG. 8:17. Using the Profilometer to check surface finish of a ground pin.

tooling, speed, feed, and other factors affecting the quality of finish are adjusted. Further production is then controlled by feel comparison. Fingernail comparison will readily indicate whether the work is smoother or rougher than the control piece for nearly all inspection purposes. Marginal cases can be compared by instruments, and in those cases where ranges such as 40 to 100 microinches are specified, fingernail comparison with specimen surfaces approximating those limits should usually be satisfactory. When close roughness tolerances are called for, or on very fine finishes, instrument comparison may be necessary.

In those cases where the part is of small diameter, it is advisable to use a wire in making the comparison in order to secure an equal point of contact on the surface of the gage and of the part. In making a

comparison of the surface of a heavy part, more accuracy can be obtained by laying the *Surf-chek* gage on a solid surface.

From an inspection standpoint, the preferred NAS–30 roughness numbers may be divided into the following two groups:

The noncritical range: 500 and 250. These surfaces are specified only when it is necessary to remove metal in order to size a part quickly, and where the surface finish is relatively unimportant.

The critical range: 100, 40, 20, 10, and 5. These surfaces are made smoother than normal rapid machining operations would produce. Finish compliance for these surfaces is very important. Any surface with a roughness of 20 or less is quite sensitive to imperfections, and should be perfectly free from toolmarks, scores, scratches, or any other type of flaw in order to function properly.

CHAPTER 9
GAGES

Gages can be grouped into two broad classifications of *fixed size* and *adjustable*. The former classification involves relatively few gage types, principally plain and threaded plug and ring gages. The latter classification, which involves a multitude of standard and special-purpose arrangements, may be further subdivided into *indicating* and *limit* gages. A representative form of each basic gage is considered in this chapter.

FIXED-SIZE GAGES

The fixed-size gage, the conventional plug or ring, is the simplest and obviously the least expensive form of gage.[1] But fixed-size gages have their limitations. First, they are *limit gages,* indicating only whether the dimension is acceptable and not evaluating actual deviations from the nominal dimension.

Fixed-size gages are made for just one dimension, external or internal. When it is no longer necessary to check that dimension, the gage at once becomes obsolete, regardless of its dimensional accuracy. Accuracy of the results obtained when inspecting is done with fixed-size gages depends to some extent upon interpretation of the "feel" of the gage by its users. Careless use may result in jamming the gage, with resultant damage to both gage and work.[2]

All fixed-size gages sustain an increment of wear; that is, they become slightly smaller or larger each time they are used. Consequently, their useful life is limited to the number of gagings required to alter the gage size beyond the permissible wear allowance. Because of this wear, it is necessary to check all fixed-

[1] Certain gage information in this chapter is derived from "Dimensional Control," The Sheffield Corp., Dayton, Ohio, 1942.

[2] The term "work," as used in this chapter, signifies the dimension being gaged.

size gages frequently, to make certain they are still within wear-allowance limits.

The practical limitations encountered with fixed-size gages are obvious, upon examination of conditions normal to their usage. For instance, a plain plug gage will, when properly handled, permit an inspector to judge whether the bore being gaged will assemble with a shaft of known diameter; but it will not indicate whether the bore is out of round, bellmouthed, or irregular in shape. Unless both *go* and *not-go* plugs are used, it cannot even be ascertained whether the hole is oversize, only that it is not undersize.

The fixed-size gage is especially useful in checking threads for proper pitch diameter and, in fact, is probably the only practicable means of production checking of internal threads, such as tapped holes. For a majority of other gaging work, adjustable gages of various types are generally more satisfactory. The adjustable gage rarely becomes obsolete, for as the work changes, the basic gage setting can be altered accordingly. Normal wear of gaging surfaces can be compensated by periodically resetting the gage to a master, or to gage blocks. In the selecting of gages, a careful analysis should be made of the relative cost of fixed and adjustable gages. This, to be realistic, must take into account not only the initial cost of gaging equipment, but also maintenance and replacement costs over the time span during which the gages will be required.

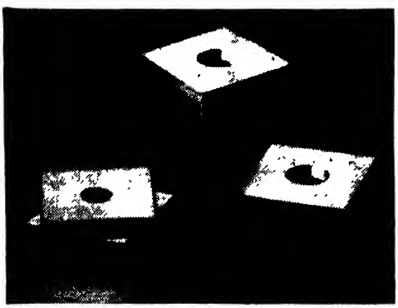


Fig. 9:1. Hoke precision gage blocks. (*Courtesy of Pratt & Whitney Division, Niles-Bement-Pond Company.*)

Gage Blocks

Precision gage blocks can be considered the genesis of all gaging work. These are blocks of special hardened steel (see Figs. 9:1 and 9:2) with two gaging surfaces. These surfaces are guaranteed by their manufacturer to be flat and parallel, and the block to be of accurate thickness within a few millionths (0.000001 in.) of an inch. The

almost perfect accuracy of every individual block permits the combination of several blocks into a stack whose total accumulated error is too small to be determined except with laboratory measuring equipment.

The *Hoke precision gage blocks* shown in Fig. 9:1 are a product of Pratt & Whitney Division of Niles-Bement-Pond Company, and differ from earlier gage blocks in that the gaging surfaces have a square, rather than oblong, surface and a central hole piercing the block from gage surface to gage surface. The square section is said to allow the blocks to be handled more readily and to reduce wear by overcoming possible tendencies to wring[3] the gage blocks together, always in one direction. The countersunk hole through the center of Hoke blocks permits the use of internal tie rods, by which rapid, compact assembling of various attachments is possible and the use of outside clamps is avoided.

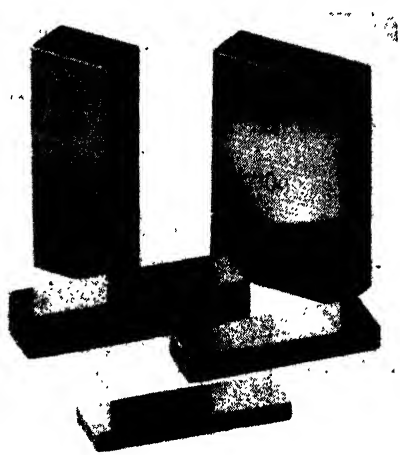


FIG. 9:2. USA precision gage blocks. (*Courtesy of Pratt & Whitney Division, Niles-Bement-Pond Company.*)

USA precision gage blocks, produced by Pratt & Whitney Division of Niles-Bement-Pond Company, are shown in Fig. 9:2. These are rectangular in shape, solid in section, and of standard dimensions for rectangular blocks. This makes possible their use as replacements in gage-block sets produced

[3] "Wringing" gage blocks together refers to the normal method of joining blocks to form a stack of the required dimension by carefully sliding the gaging surfaces together under hand pressure. When this is properly accomplished, the "wrung" stack of blocks will remain joined without mechanical support and may be lifted from the surface plate without separating. This wringing action is a characteristic of perfectly true, mirrorlike surfaces and is a positive check on the accuracy and cleanliness of the gage-block surfaces. The force which holds the blocks together is a good many times greater than the force of atmospheric pressure and is not magnetic. Its exact nature is unknown. The longer the blocks remain wrung together, the tighter they will adhere to each other. It is best to separate all blocks at the end of each day.

by other manufacturers. These blocks have the same degree of accuracy as Hoke blocks, differing only in basic shape and absence of a hole piercing the gaging surfaces.

Both forms of gage blocks are normally supplied in sets providing wide selections of dimensional increments. Individual blocks can also be obtained in a variety of sizes, ranging from 0.010 to 20.000 in. Certain of the blocks are in ten-thousandths and hundred-thousandths of an inch, permitting the building up of an infinite variation of dimensions through selection of proper block combinations.

Cylindrical Plug and Ring Gages

Cylindrical plug and ring gages, which represent an elementary form of fixed-size gage, are used to check diameters of straight

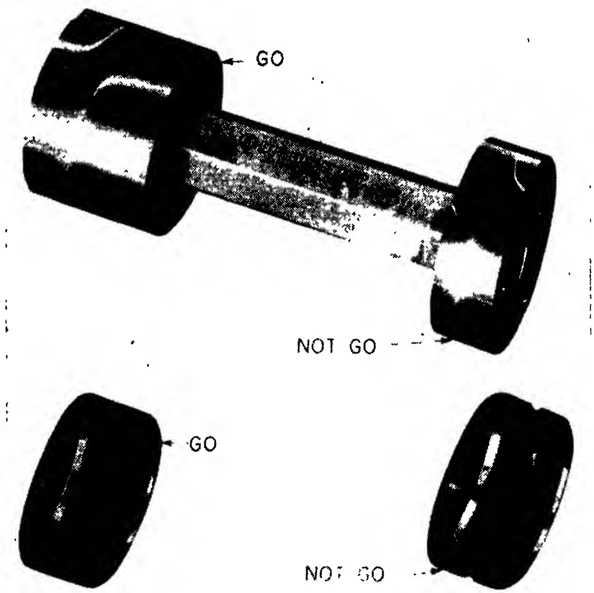


Fig. 9:3. Go and not-go cylindrical plug and ring gages. (*Courtesy of The Sheffield Corporation.*)

holes and shafts. To be of value for inspection purposes, there must be both a *go* and a *not-go* (see Fig. 9:3) gage for each diameter to be checked.

In the case of internal diameters (holes) the *go* gage checks the minimum tolerance limits, and the *not-go* gage checks the maximum limit (see Fig. 9:4). For external diameters (shafts, etc.) the reverse is true. The basic function of these gages is to control the dimensions of mating parts, thus insuring interchangeability. Any part that will receive the *go* gage should assemble properly.

Cylindrical plug gages are used for checking machined holes. Cylindrical ring gages are used for checking outside diameters. A plain ring is used for sizes up to 1.510 in. A flanged ring, economizing on weight, is normally used for diameters of 1.510 in. and larger. *Not-go* ring gages are normally identified by an annular groove in the outside diameter (see Fig. 9:3).

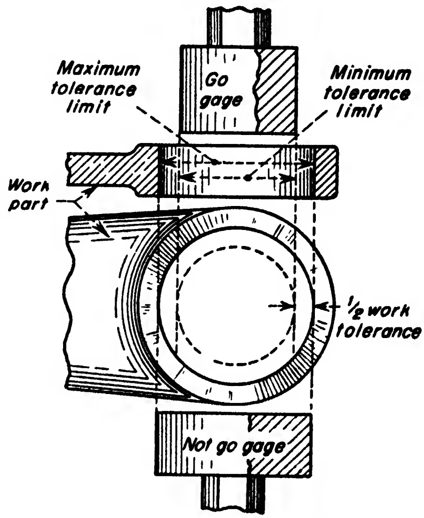


FIG. 9:4. Dimensional relationship of go and not-go plug gages. (*Courtesy of The Sheffield Corporation.*)

A special design for a cylindrical plug gage is shown in Fig. 9:5. This is the Pratt & Whitney "Pilot" gage, said to eliminate difficulties from cylindrical gages' jamming through misalignment. This problem is often encountered when the total hole tolerance is minute and the gage-element diameter may be only 0.0001 in. smaller than the hole being gaged. It is claimed that the combination of chamfer and annular groove at the entering end of the Pilot gage element prevents jamming the gage through misalignment upon insertion.

Plug and ring gages are used also for checking splines and serrations; square, rectangular, and similar shapes; and straight or taper threads. In all cases the go and not-go principle is employed, although in some instances, such as rectangular shapes, two or more not-go gages may be required to check all dimensions involved; or in the case of tapers the go and not-go limits may be on the same gage and be indicated by appropriate flats.

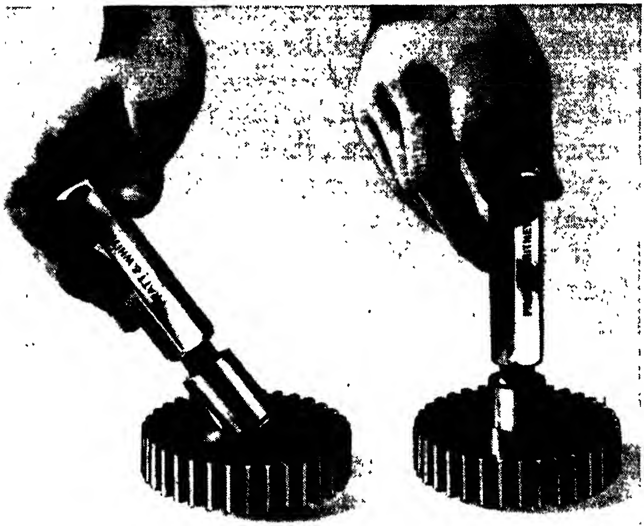


FIG. 9:5. Pratt & Whitney "Pilot" cylindrical plug gage. (*Courtesy of Pratt & Whitney Division, Niles-Bement-Pond Company.*)

THREAD PLUG AND RING GAGES

The plug-gage assembly for checking straight threads shown in Fig. 9:6 is a common form of thread gage. This consists of a go element and a not-go element joined by a hexagonal gage handle. The elements are readily detachable from the handle for replace-

FIG. 9:6. Go and not-go straight-thread plug gage assembly. (*Courtesy of Pratt & Whitney Division, Niles-Bement-Pond Company.*)

ment. The same theory of go and not-go gaging described for cylindrical plug gages is employed with straight thread gages, except that the *pitch-diameter* tolerance is used as the basis for gaging. The go element is longer than the not-go to provide ready identification.

Thread ring gages are similar in appearance and usage to plain

ring gages. Many thread ring gages are adjustable, to compensate for wear, being adjusted to master setting plugs.

Various pipe-thread forms are in use. Their gaging is more complex than for straight threads, owing to pipe threads being cut on a taper. It is desirable to check not only the pitch diameter,

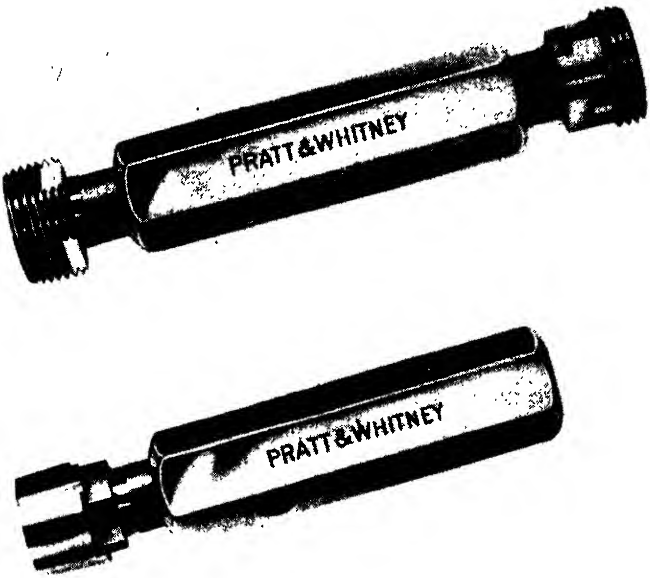


FIG. 9:7. Gages for checking ANPT internal pipe threads. (*Courtesy of Pratt & Whitney Division, Niles-Bement-Pond Company.*)

lead, and taper, but also the major and minor diameters, to insure proper engagement of the threaded elements.

Of the various pipe-thread forms, the Army-Navy Aeronautical Standard (ANPT) is probably the most exacting, and the gages required to check this thread are typical of the highest precision pipe-thread gaging practice. In Fig. 9:7 are shown Pratt & Whitney gages required for checking a given size of ANPT internal pipe thread. Three gage elements are used—two threaded plugs and one plain taper plug.

The threaded element at the left in Fig. 9:7 checks the diameter, lead, form, and taper of the entering portion of the thread, which will normally be engaged by hand pressure as the parts

are screwed together. The other end of this gage is a threaded element for checking the same characteristics of the thread farther in, at the threads that will be engaged by wrench pressure as the joint is tightened. The plain taper plug is used to check taper, roundness, and the diameter at the crest of the threads.

Each gage element has flats milled on its periphery at the back edge, to indicate by the depth of engagement whether the thread should be classed as *minimum, basic,* or *maximum.* To be acceptable, the degree of engagement of all three elements must show the same class of thread within half a turn.

A corresponding set of ring gages is used to check ANPT external pipe threads, or a pair of special roll gages may be employed. One of these roll gages comprises a plate or base supporting three tapered rollers equally spaced around a spring-loaded plunger. The gage is placed over the threads, with the end of the threaded member resting on the plunger, which extends through the gage base. Machined steps on the plunger provide a reading on the taper, and the diameter of the threads at the crest. A similar tri-roll gage, provided with steps on the upper surface of the base plate (instead of the spring-loaded plunger), checks lead, taper, pitch diameter, and form of the threads.

The extreme precision of ANPT threads requires that the areas to receive threads be accurately machined prior to threading. Plain tapered plug and ring gages are normally used to check these areas.

GAGE WEAR

Every time a plug gage is inserted into a hole or a ring gage is passed over a part, it sustains wear that decreases the diameter of the plug or increases the diameter of the ring. This wear eventually accumulates to a point at which the gage must be discarded.

The rapidity of wear is governed by the hardness of the gage surface and the care with which it is used. Gages are normally available with either hardened-steel or hard-chrome plated surfaces. Special gage elements made with cemented-carbide surfaces are also available. As cemented-carbide gages are compara-

tively expensive, extensive use of them should not be contemplated unless careful tests conclusively prove that the additional cost can be amply justified by increased gage life. In general, it has been found that the use of hard-chrome plated gages, particularly for plug elements, is economical, as their useful gaging life will exceed that of a plain steel plug by approximately 300 per cent.

Gage usage is much more important than gage-element material. Gages can be worn beyond the allowable wear limit in less than 8 hr of usage through improper handling. This is particularly true in the case of thread gages, where failure to clean the threads of chips, prior to application of the gage, or failure to lubricate the gage before each usage will wear out the best gage element in a short time. Another common abuse of thread gages in the factory is insertion and removal of plug gages in parts that are held in a lathe by applying power to the chuck. This not only may jam the gage during insertion but causes excessive friction on the gage threads during both operations.

Average gage life can often be increased threefold by establishing positive rules regarding the cleaning, lubrication, and application of gages in all departments of the factory. Once these rules are established, it should be made the responsibility of each supervisor to see that they are faithfully followed.

ADJUSTABLE GAGES

Adjustable gages do not suffer from the limitations of fixed-size gages, being capable of variation of the gaging dimension. Thus they escape obsolescence through product changes. All gages wear with usage. The adjustable gage, however, may be periodically corrected for normal wear, while the fixed-size gage must either be discarded or reworked when worn beyond the allowable limit.

In a broad sense there are two types of adjustable gages: *limit* and *indicating*. This classification has no relation to the mechanics of the gage but relates to the type of information it provides. Limit gages indicate whether or not the work is within the total tolerance and, if not, whether it is underside or overside. *They do not evaluate the measurement.* Indicating gages, on the

other hand, evaluate the measurement and show the actual dimension existing at the point being measured.

Snap Gages

The *snap gage* (see Figs. 9:8 and 9:9) is one of the most simple forms of adjustable gages. A combination of a C frame with one fixed and two adjustable anvils provides for setting the gage to selected go and not-go limits on external dimensions.

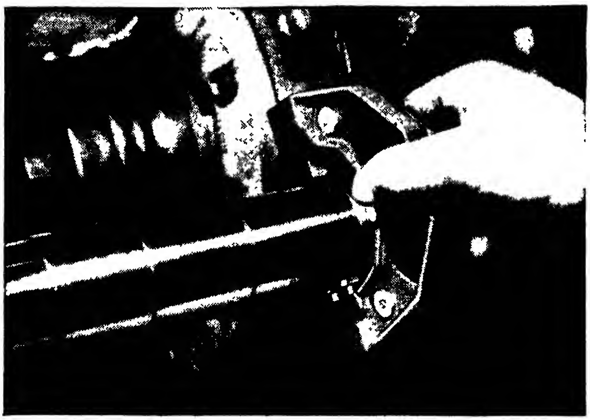


Fig. 9:8. Adjustable-limit snap gage used to check a ground shaft. (*Courtesy of Pratt & Whitney Division, Niles-Bement-Pond Company.*)

Snap gages have a distinct advantage over conventional go and not-go ring gages when certain external diameters are being checked. For instance, for checking a long shaft having a critical diameter throughout its length it is preferable to use a go ring gage and a not-go snap gage. It is possible for the shaft to have a larger diameter at its ends than at some intermediate point, and this condition might not be detected if ring gages only were used for checking. A not-go ring gage would not pass over the shaft ends, and a defective part would be accepted. A snap gage, on the other hand, could be used to check the shaft throughout its length and would immediately detect the error. A snap gage would also be faster to operate and might be less expensive than a ring gage.

A basic advantage of the snap gage is its ability to check work while it is in the turning, grinding, or threading machine.

Snap gages should be set and sealed by the gage-control group and should be given to the inspector or the machinist ready for use. This takes away all responsibility from the user and eliminates his natural and expensive tendency to work to nominal dimensions. The snap gage provides the working limits in a rigid, unmistakable form; and possible errors arising from misreading measuring instruments are eliminated.

The total adjustment provided in a snap gage is approximately ¼ in., making possible checking of a large number of dimensions with a small variety of gages. Setting plugs (sometimes called "master disks"), combining go and not-go dimensions, can be ob-

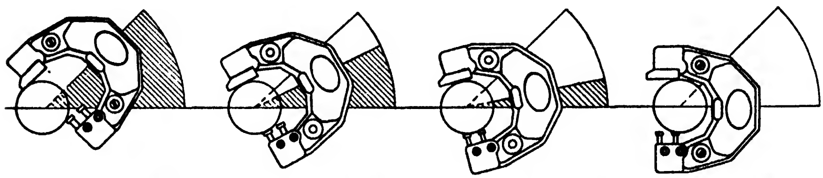


FIG. 9:9. Operating principles of a typical snap gage. (*Courtesy of Pratt & Whitney Division, Niles-Bement-Pond Company.*)

tained for the purpose of setting snap gages quickly to selected dimensions. These are genuine timesavers when a large quantity of gages must be set to the same dimensions for large production runs and must then be rechecked periodically. Gage blocks are used for setting and checking snap gages to exact limits in cases where usage does not justify the expense of setting plugs.

Dial Indicator Snap Gage

A variation of the conventional snap gage is seen in the *dial indicator snap gage* shown in Fig. 9:10. This provides an indication of the exact variation in dimension by setting the gage for zero reading on the nominal dimension. The plus or minus variation from the nominal can then be read directly on the dial, within the limits of the gage, which are ordinarily ± 0.005 in.

This gage, like practically all other dial indicator devices, is not desirable for work in which the total tolerance is less than 0.001

in. Many manufacturers of dial indicators claim their products to be accurate to 0.0001 in. While this is undoubtedly true of a new instrument in the hands of a skilled operator, it is equally true that total tolerances of less than one-thousandth of an inch usually require checking by gages or measuring instruments of higher precision.

The dial indicator snap gage shown in Fig. 9:10 is available in 12 standard models, covering a range up to 12 in. The stationary

FIG. 9:10. Dial indicator snap gage supported in bench stand. (*Courtesy of The Sheffield Corporation.*)

anvil of each model is adjustable up to a maximum range of 1 in. A gage stand is available for certain models, to facilitate the bench checking of small parts. All these gages are available with handgrips, for use without the stand.

Roll Thread Snap Gages

Snap gages are also used in the place of ring gages for checking external, or male, threads. Go and not-go gaging rolls are rotatably mounted on eccentric adjusting pins supported in a U frame (see Fig. 9:11). Having go and not-go dimensions combined in a single unit greatly reduces gaging time, as both limits can be checked in a single operation. A distinct advantage of the gage shown in Fig. 9:11 is its ability to check both left- and right-hand threads, because the gaging rolls are annular rather than spiral. That is, the gage elements are parallel ribs or fins having their periphery ground to the proper form for checking threads, rather

Fig. 9:11. Checking studs with roll-thread snap gage. (*Courtesy of Pratt & Whitney Division, Niles-Bement-Pond Company.*)

than the continuous spiral of a thread. Unless this were done, it would be impractical to pass the threaded member through the go rolls.

Many kinds of errors can cause thread failures, and these may be present even in threads that will assemble. This indicates the need for a thread-inspection device that will go beyond mere indication of interchangeability, to detect and expose all possible thread errors. The roll thread snap gage shown in Fig. 9:11 provides an analysis of screw-thread errors, including lead, pitch diameter, form (angle), out-of-roundness, and straightness.

The go rolls have a number of annular ribs, which engage the thread over a considerable portion of its length and check for

periodic and accumulative lead errors. This check is made through visual inspection of the thread engaged in the rolls. Defective lead is immediately apparent by the thread's "riding" the rolls in an unequal manner.

Verification that the thread pitch diameter does not exceed the maximum and minimum limits is provided by the go and not-go rolls. The threaded member should pass through the former and stop at the latter.

Passing the threaded member from the go to the not-go rolls will detect errors in thread form or angle through simple visual inspection. The go rolls have a full thread-form profile, while the not-go rolls have a modified profile, involving a flat-top, narrow form.

Out-of-roundness and ovality can be tested by rotating the threaded member a quarter turn while it is in contact with the not-go rolls. If the thread is undersize at any diameter, it will drop through the not-go rolls. If the newly presented diameter is oversize, the thread cannot be withdrawn through the go rolls.

The straightness of a screw thread can be tested by successively bringing both ends of the thread into contact with the not-go rolls, which will detect an undersize condition. An oversize condition at any point can be checked in a similar manner by using the go rolls.

Setting plugs and bars are used for adjusting and checking roll-thread snap gages. Plugs are used for smaller gages, while bars having roll thread elements at each end are used for large gages. The use of a bar in these latter cases avoids the expense of a large, heavy setting plug.

The secret of obtaining proper results with this gage, as with practically every other piece of inspection equipment, lies in educating all inspectors and machinists in its proper usage. In the case of any type of *limit* snap gages it is necessary to make certain that each gage user knows the *maximum pressure* to apply in using the gage on both go and not-go elements. It is of no account to adjust a snap gage perfectly and then have an operator force parts through the gage by using excessive pressure.

Dial Indicator Thread Snap Gage

The Sheffield "Thredchek," shown in Fig. 9:12, is an example of a roll thread snap gage equipped with a dial indicator to provide positive measurement of the magnitude of possible error in pitch diameter. The go rolls are set to the proper value with a go setting plug, and they simulate normal assembly conditions. All externally threaded parts that pass through the go rolls will assemble properly with their mating parts. This gage is made in both bench (as shown) and hand-held forms.

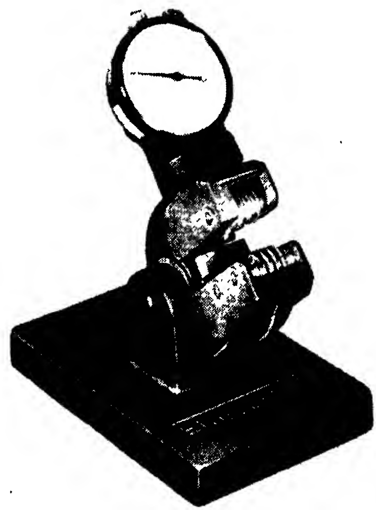


Fig. 9:12. The Thredchek, a dial indicator roll-thread snap gage. (*Courtesy of The Sheffield Corporation.*)

Parts that are accepted by the go rolls are then passed between the not-go rolls, to rest firmly against a backstop adjusted to represent the thread mean outside diameter. The dial indicator then gives an accurate reading of the pitch diameter, providing a definite basis for acceptance or rejection of the part. This feature of readily obtaining a reading on the pitch diameter is important when precision threads are involved, as these usually specify exact pitch-diameter limits.

Out-of-roundness can be measured by holding the threaded member against the backstop while it is being revolved between the not-go rolls. The presence and exact magnitude of out-of-roundness is positively indicated by deflection of the dial indicator.

Lead, thread form, and straightness can be tested on the Thredchek by procedures similar to those described for nonindicating (limit) roll thread snap gages. The not-go section of the gage is limited to two ribs on each roller, in keeping with conventional thread snap-gage design.

REMOTE INDICATING, MAGNIFYING SNAP GAGE

The various snap gages described in foregoing paragraphs obtain dimensional indication either by feel or through a mechanical dial indicator providing modest magnification and fair accuracy. These are the conventional forms of snap gages, used for many years for production and inspection checking.

In recent years several gage manufacturers have developed electric gaging systems wherein the movement of preloaded gage anvils causes proportional variations in the current flowing through an electric circuit. These current variations produce corresponding fluctuations in a microammeter (or similar indicating device), which can be read as dimensional variations on an instrument dial calibrated in ten-thousandths of an inch.

The electric gaging system lends itself to interesting and novel applications. Not only may the indicating instrument be remote from the gaging head, but any reasonable degree of precise magnification may be introduced into the system. Thus, the indicating instrument may be accurately calibrated in ten-thousandths or even hundred-thousandths of an inch.

In some cases several gaging heads are assembled into a fixture to provide checking several dimensions as one operation (see Fig. 9:29). This may be accomplished simultaneously, through use of an indicator for each dimension to be checked, or a selector switch and one indicator may be used for progressive checking of the several dimensions.

The Pratt & Whitney Electrolimit snap gage is an example of a remote-indicating, magnifying gage, which can be set to the required size by a master standard and then used to measure variations from standard of actual production parts, within the plus and minus limits of the indicator.

Instruments of this nature do not ordinarily employ go and not-go anvils, as these are indicating,[4] rather than limit, gages. Their indicating range, however, is small. The Pratt & Whitney Electrolimit snap gage shown in Fig. 9:13 has a normal full-scale

[4] For the purpose of this discussion, any gage that evaluates a measurement is considered an indicating gage, regardless of how small the range of evaluation may be.

indication of 0.002 in. (plus and minus 0.001 in.), although the gage may also be obtained with a full scale of 0.001, 0.003, or 0.004 in. (see Fig. 9:14).

The Electrolimit snap-gage measuring anvils are set to the desired nominal dimension in exactly the same manner as a conventional snap gage. Final adjustment for zero reading is accomplished by the zero-setting knob on the indicating instrument.

Fig. 9:13. Electrolimit snap gage used to check diameter of a part while in grinding machine. (*Courtesy of Pratt & Whitney Division, Niles-Bement-Pond Company.*)

The backstop can be adjusted either to provide high-point reading upon the work touching the backstop or for engagement beyond the high point. With the latter adjustment, it is necessary to rock the gage slightly to find the high point or largest diameter.

The basic elements and electrical circuits used in this gage are identical with those employed in the design of a variety of Pratt & Whitney Electrolimit remote-indicating, magnifying gages. In

all cases the gage installation comprises essentially three units: the gaging head, the power supply, and the microammeter. The basic circuit diagram for this system is shown in Fig. 9:15.

Magnification of movement is obtained by unbalancing an inductance bridge circuit. Two of the inductances are small coils in

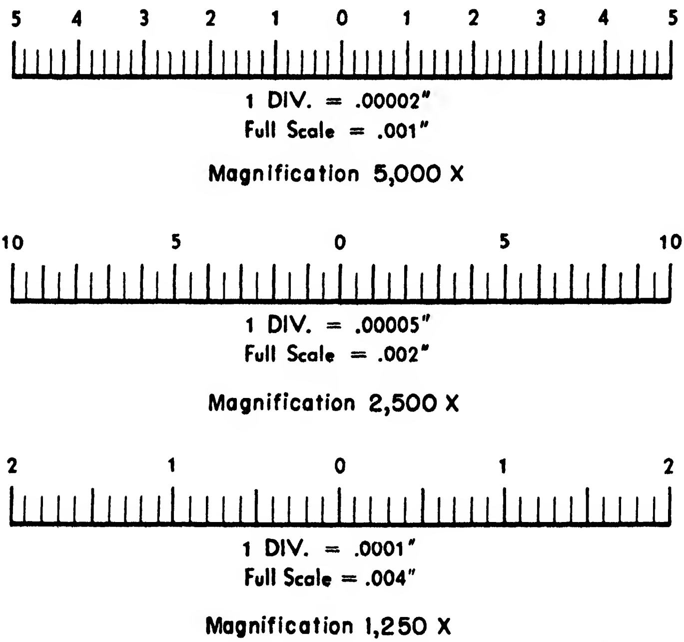


FIG. 9:14. Typical scale graduations for Electrolimit indicating instruments. (*Courtesy of Pratt & Whitney Division, Niles-Bement-Pond Company.*)

the gaging head. The inductance values of these coils are varied by the movement of an armature actuated by the gaging spindle carrying the movable anvil.

The other two inductances of the bridge,[5] together with a voltage regulator, a power transformer, and a meter current rectifier, comprise the power supply unit. Potentiometers provide for adjusting zero scale setting and magnification.

Precision-setting disks are normally used to adjust the gaging head to the desired nominal dimension, although gage blocks may

[5] A variation of this circuit employs a bridge of two inductances (coils) and two capacitors (condensers).

be employed. Once the gage has been adjusted, its operation is not particularly different from that of a dial indicator snap gage, except that a much higher degree of accuracy should be obtained. As in the cases of a majority of precision electrical measuring instruments, a warm-up period of ½ hr. should be allowed before

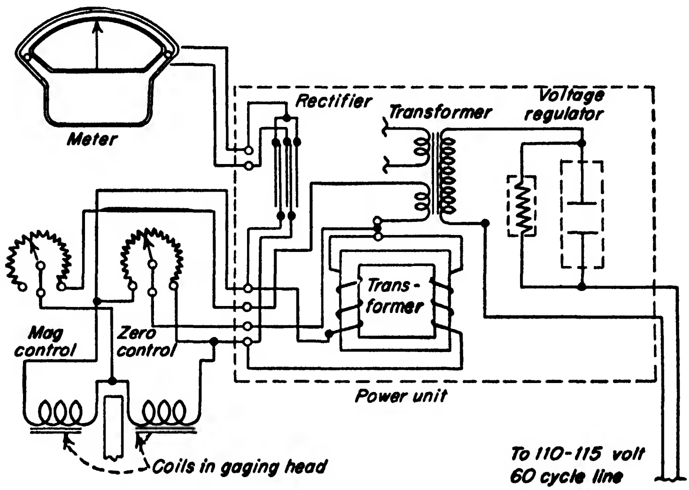


FIG. 9:15. Basic circuit for Electrolimit gage installation. (*Courtesy of Pratt & Whitney Division, Niles-Bement-Pond Company.*)

using the gage; and the accuracy of the instrument will be affected by substantial line-voltage variations.

HEIGHT GAGE

A height gage is probably the commonest and most useful article of inspection equipment. It is used to check runout and concentricity of parts or to measure the height of a point above a base common to the gage and the article being checked. Also, with the height gage it is possible to transfer dimensions from a stack of gage blocks to the point being checked. This is done by placing both the part to be checked and the height gage on an accurate surface plate. When the proper dimension from the plate to any point on the part above the plate is known, this dimension can be built up with gage blocks placed on the surface plate. Then by the use of a height gage (comprising essentially a base, a vertical column, and an adjustable crossarm carrying a

tracer point), the gage-block dimension can be transferred to the point to be checked.

The most elementary form of height gage simply provides for verifying or transferring the accuracy of set dimensions and does not evaluate the magnitude of variations from the selected di-

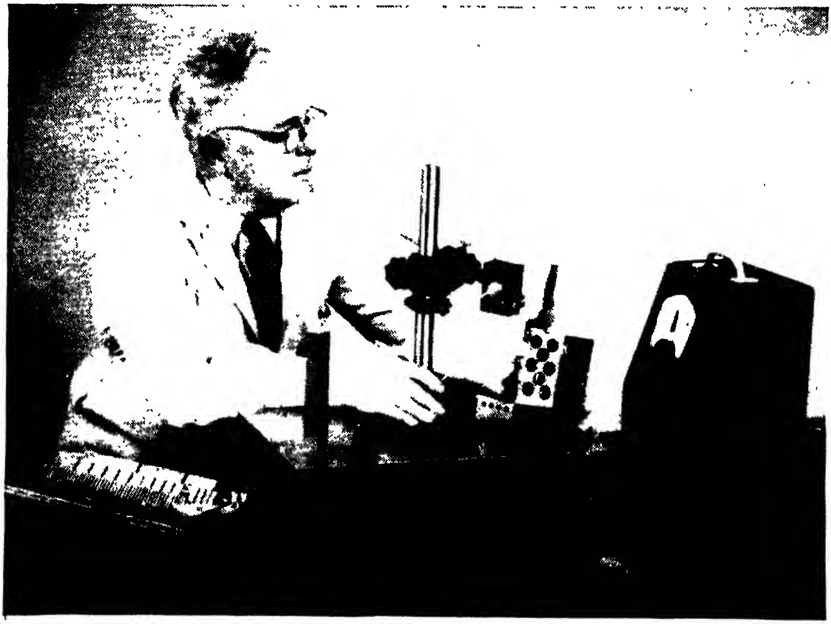


FIG. 9:16. Using an Electrolimit Height gage to transfer an exact dimension from a stack of Hoke gage blocks to check the profile of a railroad gage. (*Courtesy of Pratt & Whitney Division, Niles-Bement-Pond Company.*)

mension. This deficiency can be corrected through use of a *vernier height gage* for measurements when the tolerance is not less than 0.001 in.

When highly accurate height gage measurements are necessary, a remote indicating, magnifying instrument similar to the Pratt & Whitney Electrolimit height gage shown in Fig. 9:16 is desirable. This operates on the principle previously described for the Electrolimit snap gages, except that the inductance bridge armature is connected to the height-gage tracer point, instead of to a movable anvil. Meter scales, magnification, and sensitivity are practically identical.

INDICATING COMPARATORS

Various gages incorporating magnification devices (both electrical and mechanical) have been designed for the purpose of checking a set nominal dimension and indicating the plus or minus variation from this value. These can be termed *indicating comparators.*

Comparators Using Electrical Magnification

Various forms of the Pratt & Whitney Electrolimit instrument are available as indicating comparators. In all cases these use the basic principle and electrical circuits previously described for the Electrolimit snap gage and vary only in the adaptation of the gaging head to suit the type of dimension to be evaluated.

In Fig. 9:17 is shown an Electrolimit *external comparator* of a type commonly employed to check diametral and linear dimensions on production parts. For each dimension to be checked the instrument must be set with gage blocks or setting plugs. After this setting is accurately accomplished, the production inspection of that dimension becomes simply a matter of inserting the work between the instrument anvils and observing the meter indications. The instrument will indicate variations from the set dimension within the range of the meter. The accuracy of the nominal dimension setting can be checked at any time by inserting either a setting plug or a suitable stack of gage blocks.

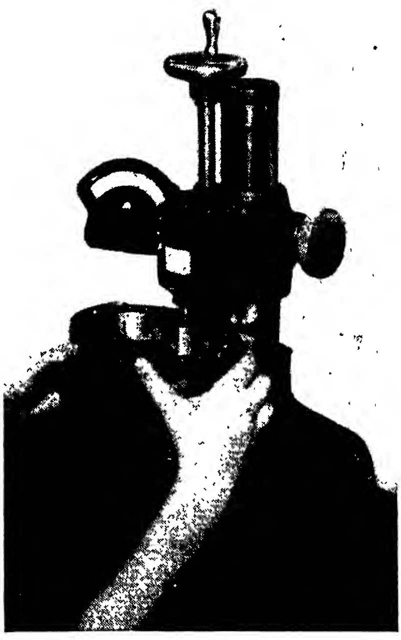


Fig. 9:17. Electrolimit indicating external comparator. (*Courtesy of Pratt & Whitney Division, Niles-Bement-Pond Company.*)

Various styles of this instrument are available, including one

model with accept and reject limit lights, in addition to the meter. This permits faster inspection, as the operator needs to refer to the meter only when the reject light is illuminated. The model shown in Fig. 9:17 is provided with the indicating meter mounted directly on the gage assembly. This is a direct indicating meter using a 3-in. scale. Other models use a meter mounted in a separate case, with a 5-in. scale, as shown in Fig. 9:14, and providing additional magnification through optical enlargement of the meter deflection.

Fig. 9:18. Electrolimit indicating internal comparator. (*Courtesy of Pratt & Whitney Division, Niles-Bement-Pond Company.*)

Only a portion of dimensions requiring measurement are external. An approximately equal quantity are internal. The Electrolimit indicating internal comparator shown in Fig. 9:18 is designed for the production inspection of internal dimensions. Its basic operating principle is identical with that of other Electrolimit instruments, involving an electrical bridge circuit, provided with electric and optical magnification, with indications obtained from a gaging spindle inserted in the bore to be checked.

Standard gaging spindles available for this instrument provide for diameters between 1/4 in. and 4 in. The gaging spindle, in conjunction with a diamond gaging point, determines the size and characteristics of the bore being checked. Each gaging spindle consists of a cylindrical body, integral with a shank or flange section for mounting it to the gage assembly. Two tungsten carbide strips are securely inserted in the spindle body. These strips are ground cylindrically to the minimum diameter of the hole to be gaged, while the spindle body itself is ground slightly smaller. The strips make contact with the hole being gaged and, together with the diamond gaging point, provide a triagonal contact between the spindle elements and the bore. Variations in hole size

cause a corresponding movement of the preloaded gaging point and actuate the electric gaging head armature to unbalance the bridge circuit and to show an accurate dimensional indication on the meter.

Gaging spindles are nonadjustable and are intended to check only a specified internal diameter. However, the spindles are readily interchangeable, and a range of internal diameters may be gaged on one instrument by providing the required spindles.

Comparators Using Mechanical Magnification

The dial indicator instrument employing mechanical magnification to obtain reasonably accurate measurements has been discussed in preceding paragraphs. In addition to this design, there are other gaging instruments that obtain extreme precision through special mechanical magnification devices. Typical of these is the Sheffield visual gage, which is an indicating comparator that can be set by gage blocks or setting plugs. It employs a combination of mechanical and optical means of translating and magnifying the movement of a gaging point. Like similar comparators, this instrument can check all internal and external dimensions normally encountered—including width, thickness, height, depth, diameter, taper, out-of-roundness, concentricity, and the angularity of surfaces or angularity between a bore and a surface, and runout. Critical elements of screw threads can also be checked.

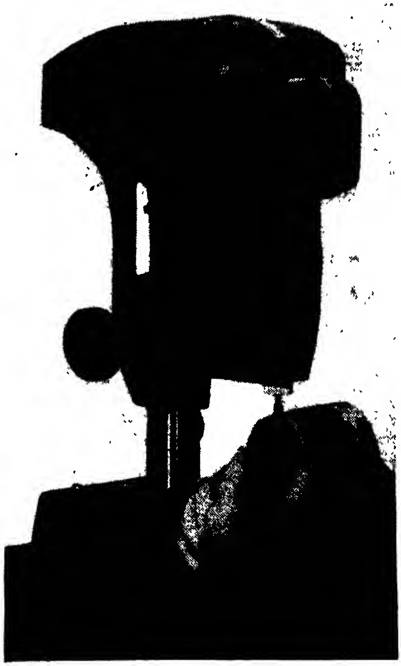


FIG. 9:19. Checking a piston diameter with a Sheffield visual indicating comparator. (*Courtesy of The Sheffield Corporation.*)

However, this comparator (like all similar gages) is primarily

useful for production inspection, as a setup must be made for each nominal dimension to be checked. The instrument must be adjusted for zero reading on a selected dimension and will then evaluate plus or minus variations from the nominal up to the limit of the gage. Measuring instruments that indicate the exact value of *any* dimension within their range without the necessity of presetting are preferable to gages for experimental inspection.

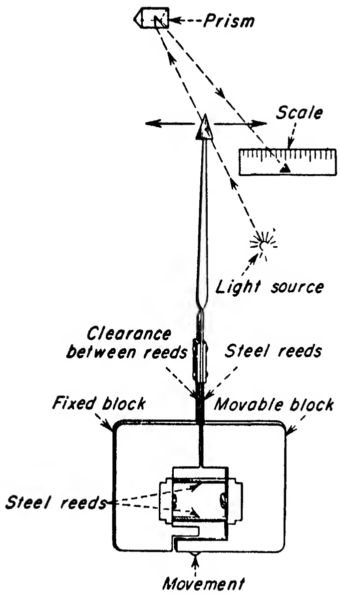


FIG. 9:20. The reed mechanism and light-beam lever arm of the Sheffield visual gage provide two stages of magnification. (*Courtesy of The Sheffield Corporation.*)

The basic mechanism of all Sheffield visual indicating comparators involves a reed mechanism (see Fig. 9:20) for magnifying small movement of the gaging point or anvil. Essentially, this device consists of two metal blocks, one fixed and one movable, joined by special-alloy steel reeds.

The fixed block is rigidly anchored to the gage-head case. The movable block, carrying the gaging spindle, is connected horizontally to the fixed block by two reeds. A vertical reed is attached at the inside top of each block. There is no contact between these reeds except at their upper ends, which are joined together. Beyond this joint extends a pointer.

The gaging point is an integral part of the movable block. When point and block are moved upward in a gaging operation, the horizontal reeds deflect slightly, but the vertical reed on the floating block tends to slip past its companion. However, as the vertical reeds are joined at their upper ends, instead of their slipping, the movement causes both reeds to swing through an arc, and as the pointer is an extension of the vertical reeds, it swings through a much wider arc. The amount of pointer swing is proportional to the distance that the floating block is moved but is much greater.

Through a series of lenses, a light beam projects the shadow of the pointer on the gage scale (see Fig. 9:21). In this manner two methods of magnification—mechanical and optical—are com-

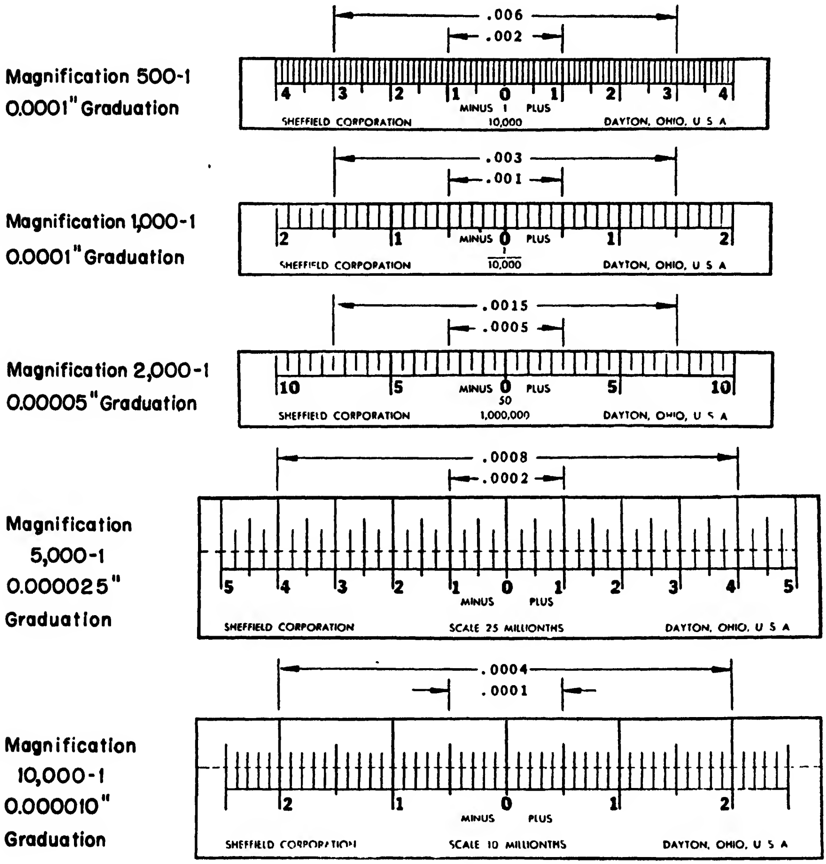


FIG. 9:21. Typical scale graduations for Sheffield visual indicating comparators.

bined. Bearing friction and backlash, common faults of many mechanical gages, are eliminated.

Sheffield visual gages are available in six different magnifications. The value best suited to a particular application is the minimum magnification that will satisfactorily handle the work, because the total scale range decreases as the magnification in-

creases. For instance, a model with 500:1 magnification provides a total scale range of 0.008 in. (± 0.004 in.), while a similar instrument with a magnification of 20,000:1 providing direct reading in millionths, has a total scale range of only 0.0005 in.

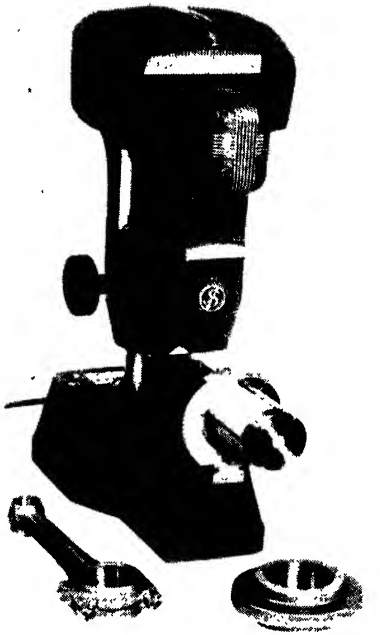


Fig. 9:22. Sheffield visual indicating comparator equipped for checking internal diameter of connecting-rod big-end bearing. Master setting ring is shown in front of gage base. (*Courtesy of The Sheffield Corporation.*)

The basic Sheffield visual gage can be used also for internal measurements when it is equipped with a gaging spindle adapter, as shown in Fig. 9:22. With this arrangement, internal diameter, taper, and out-of-roundness can be checked to the same degree of accuracy as external dimensions. Standard gaging spindles are available for diameters between 0.3115 and 6.000 in.

GAGING WITH AIR

The use of air pressure as a gaging medium has been explored for at least two decades, but its acceptance as a practical production method dates to about 1940. Air has certain basic advantages for gaging. It is readily available, safe, and rapid; it will not damage highly finished or soft surfaces; and gage wear is minimized. The basic elements of a successful air gage are a gaging spindle, an indicating instrument, a source of air pressure, and tubing to connect the pressure source to the indicator and the spindle.

Air under pressure travels through the tubing, into the gaging spindle, and along the center of the spindle, to emerge from tiny nozzles at each side. These tiny nozzles do the gaging. When the spindle is inserted into an internal diameter, the annulus formed between spindle and work serves as a restricting orifice to

limit the free escape of the air. The smaller the annulus (*i.e.*, the smaller the inside diameter), the greater is the restriction. The indicating instrument responds in exact proportion to the amount of restriction and provides an extremely accurate measurement of the internal diameter. Moving the spindle along the inside diameter provides rapid checking of taper, out-of-round, and diametral limits. This type of instrument is unusually well adapted to the inspection of bores such as gun barrels and hydraulic cylinders that are too long or too small for practical checking by conventional means.

An almost unbelievable degree of accuracy can be obtained through air gaging. Production air gages have been constructed for checking tolerances as small as 0.00001 in.

There are two basic principles utilized in the design of air gages. One employs the *back pressure* resulting from the restricting-orifice effect of spindle and work. The other utilizes measurement of the *rate of flow* of air passing between spindle and work. It is obvious that variations in the orifice annulus created by spindle and work will directly affect both back pressure and rate of flow.

The elements of a back-pressure air gage are illustrated in

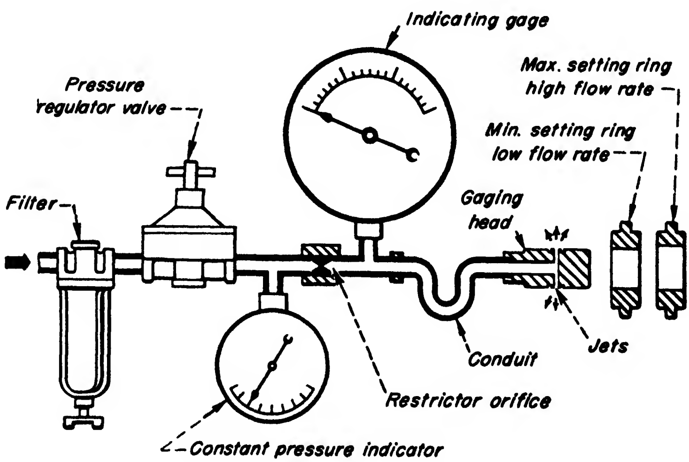


FIG. 9:23. Elements of back-pressure air gage. Back pressure is controlled by ratio of orifice to air escaping when gaging spindle is inserted in diameter to be checked. Indication is compared with known values obtained with minimum and maximum setting rings. (*Courtesy of The Sheffield Corporation.*)

Fig. 9:23. This design is frequently employed, but it is considered by some to be less adaptable than the rate-of-flow type of instrument, owing to the necessity of waiting for the air column to stabilize before an accurate reading can be obtained. This factor is negligible when gaging spindle and indicating instrument are parts of the same unit (see Fig. 9:25), but it may become significant when the spindle is remote from the indicator (see Fig. 9:28).

In Fig. 9:24 the elements of a rate-of-flow air gage are illustrated. This operates on a basis of varying air velocities at constant pressure. In a column of air flowing at constant pressure, the quantity of air, by weight, passing any point at any instant

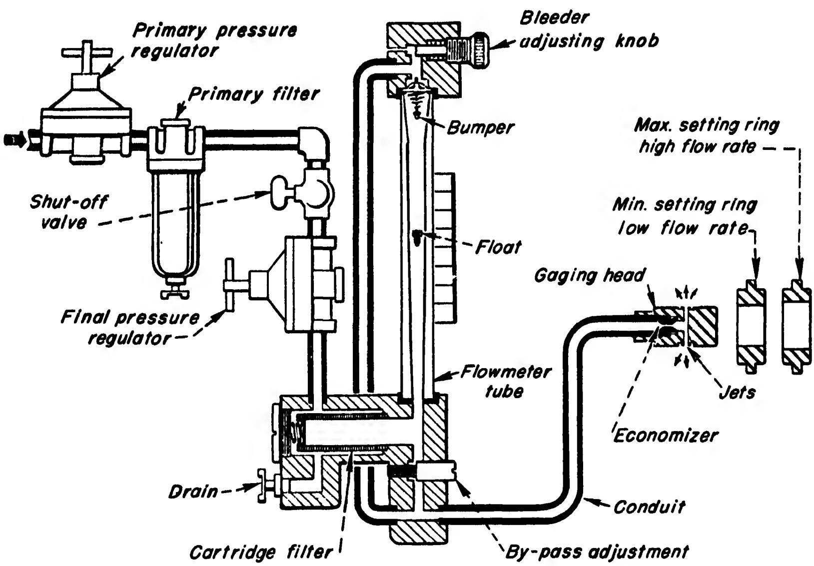


FIG. 9:24. Elements of constant-pressure rate-of-flow air gage. Dimensional indication is provided by movement of flow-meter float suspended by moving air column. (*Courtesy of The Sheffield Corporation.*)

is the same, regardless of the length of the column. Thus, with a rate-of-flow instrument, it makes no difference how far the gaging spindle and the indicating instrument may be separated. The gaging spindle may be an integral part of the gage assembly or it may be at the end of a long length of flexible tubing. Instantaneous gaging indications will be obtained in either case.

COMMERCIAL AIR GAGES

Commercial air gages are made in a variety of forms. Among the leading manufacturers of these gages are Pratt & Whitney Division of Niles-Bement-Pond Company, which produces the Air-o-limit, a back-pressure type of gage; and The Sheffield Corporation, which manufactures the Precisionaire, a constant-pressure rate-of-flow instrument. *Both of these instruments can be classified as indicating comparators.*

It must always be taken into account when considering the use of air gages that these instruments essentially are *high-production* inspection equipment. Their use is not recommended for low production, as separate gaging units (spindle, snap, etc.) must be obtained for each dimension to be checked. These units are relatively expensive, and their cost cannot be justified unless thousands of identical parts are to be checked.

Pratt & Whitney Air-o-limit

The Pratt & Whitney Air-o-limit indicating comparator utilizes the measurement of the back pressure of air caused by limiting the discharge of air through a pair of nozzles. Basically, the instrument (see Fig. 9:25) consists of an air filter, a pressure regulator, a pressure indicator, a restrictor, a gaging indicator, and the gaging spindle. The air required for gage operation is usually obtained from the normal compressed-air supply available in the factory.

A graphic illustration of the principle of the Air-o-limit gage is shown in Fig. 9:26. Referring to this illustration, the gaging spindle has two diametrically opposed nozzles through which compressed air can escape. When the work to be gaged is placed over the gaging spindle, the amount of air discharged is restricted and the air pressure at the nozzles is increased. This pressure change is registered on a precision pressure indicator, calibrated to read in ten-thousandths of an inch or fractions thereof. This pressure change, which varies directly with the clearance between nozzles and work, provides a direct evaluation of the diameter of the work.

The Air-o-limit gage is available in various forms, including

FIG. 9:25. Air-o-limit indicating internal comparator used by grinder operator for checking size, taper, and roundness of ball-bearing races. (*Courtesy of Pratt & Whitney Division, Niles-Bement-Pond Company.*)

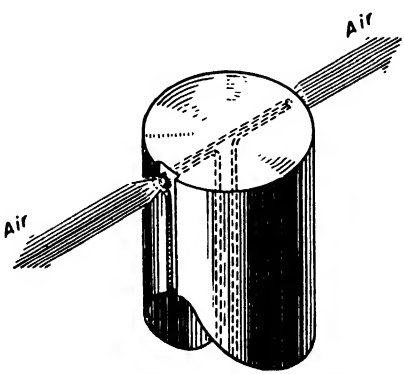
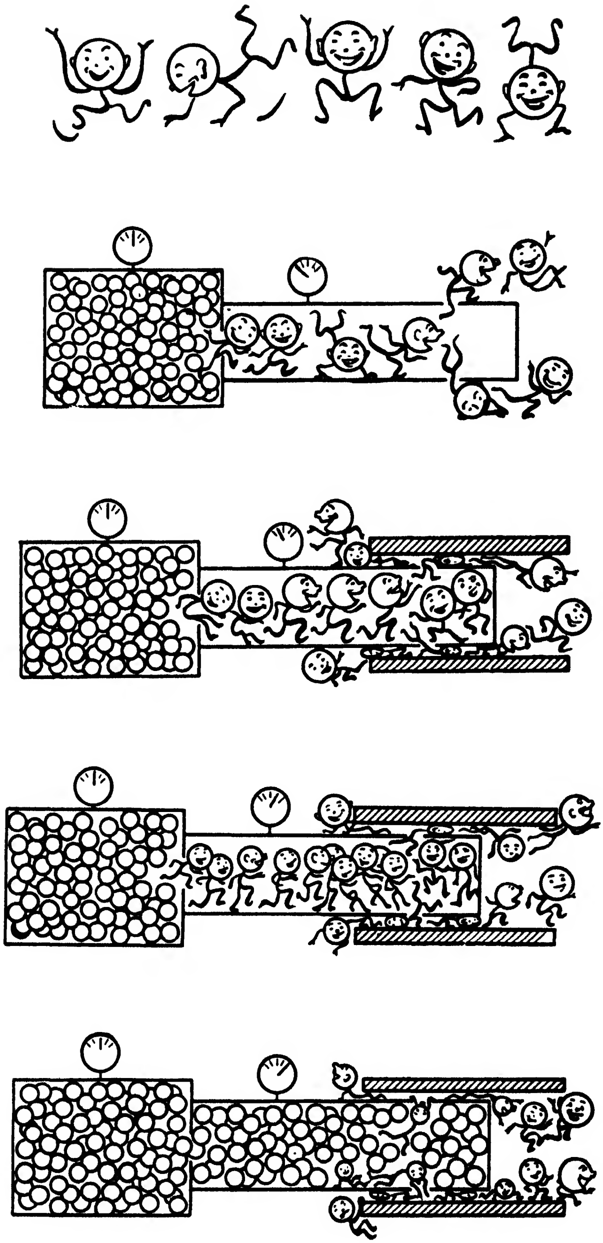


FIG. 9:26. Principle of the Air-o-limit indicating internal comparator. (*Courtesy of Pratt & Whitney Division, Niles-Bement-Pond Company.*)

Fig. 9:26 (*Continued*)



arrangements with the gaging spindle integral with the instrument assembly, as shown in Fig. 9:25, or with the spindle remote from the indicating instrument at the end of a length of flexible connecting tubing. Standard gaging spindles are available for checking internal diameters between 0.124 and 2.065 in. A variation of this device is the Air-o-limit snap gage. This utilizes the principle of air gaging to measure external diameters, through providing a single air nozzle in one of the anvils of a special snap gage. This snap gage is connected to the indicating instrument by flexible tubing and permits checking the work while it is still in the machine. These pneumatic snap gages are available for checking diameters ranging from ½ in. to 10 in.

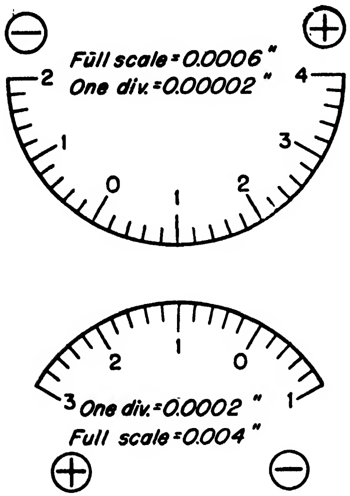


FIG. 9:27. Typical scale layouts for Air-o-limit indicating comparator. (*Courtesy of Pratt & Whitney Division, Niles-Bement-Pond Company.*)

Conventional plus and minus comparator scales are used on the Air-o-limit indicating gage. Standard scale layouts provide for full-scale (sum of plus and minus) ranges of 0.0006 to 0.004 in. with calibration increments of 0.00002 to 0.0002 in. (see Fig. 9:27). Adjustable limit needles are provided, which can be set at the maximum and minimum permissible limits. A third needle, connected to the gage mechanism, indicates the actual dimension when the work is gaged.

SHEFFIELD PRECISIONAIRE

The Sheffield Precisionaire air gage (see Fig. 9:28) is normally used as a limit comparator but is also available as an indicating comparator. This gage utilizes the measurement of air flow, which changes in direct proportion to variations in the work being gaged, as a means of evaluating internal and external dimensions. Basically, the instrument consists of a filter, a pressure regulator, a flowmeter (essentially comprising a precision transparent tube containing a float), and a gaging spindle or snap. The tube con-

taining the float is accurately tapered, resulting in the float's being moved upward by the air velocity to allow the amount of air that is escaping through the orifices of the gaging tool to pass.

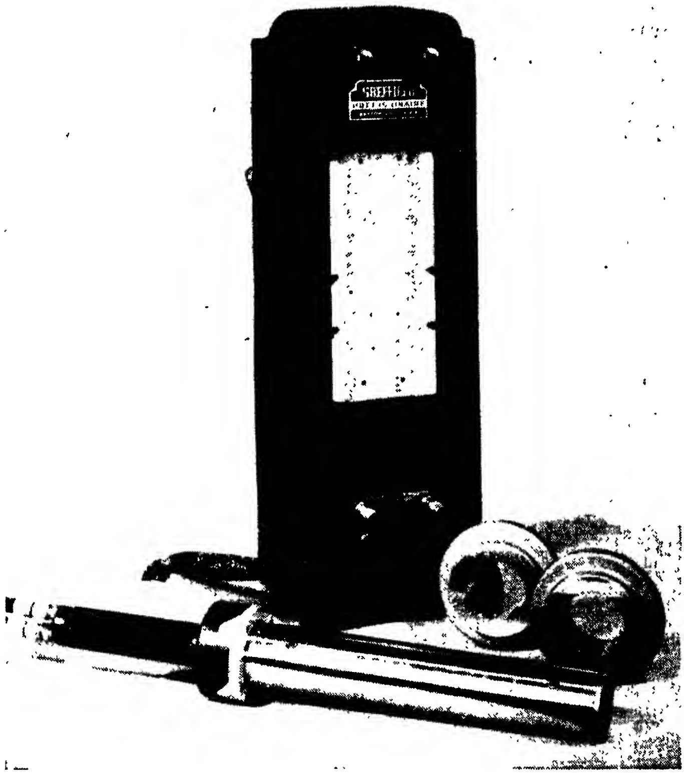


FIG. 9:28. Precisionaire indicating internal comparator with remote spindle, arranged as duplex assembly for simultaneously checking two internal diameters. Note adjustable pointers set to mark high and low limits on gage scales, and master setting rings used to set and check gages. (*Courtesy of The Sheffield Corporation.*)

The tube is indexed, to show float positions corresponding to high- and low-dimensional limits in the case of a limit comparator, or calibrated with actual plus and minus values in the case of an indicating comparator.

If, when an internal diameter is being checked, the hole is undersize, the float will drop (owing to reduced air flow) just far

enough to indicate the undersize condition. If the hole is oversize, the air flow will be greater and the float will rise to a higher position in the flowmeter tube. Thus the float position reveals the size or condition of the part being checked. When the gaging spindle or snap is not engaged with a part, the air flows freely and the float rises to the top of the flowmeter tube. The float reacts instantly to slight deviations, such as a low-spot, high-point, taper, bellmouthed, or out-of-round condition in the part being checked.

The Precisionaire is available in four models, covering a range of amplifications from 1,000:1 to 25,000:1, and provides for checking dimensions having a total tolerance of from 0.005 to 0.0002 in. The gage accuracy is substantially the same for all ranges, the only significant variation being in the spacing of calibrations on the gage scale, with corresponding variation of the smallest dimensional increment possible of direct reading.

Spindles used with the Precisionaire, like those used for other air gages, are basically similar to a conventional plug gage, but they are made with an internal longitudinal air channel leading to one or more orifices in the cylindrical surface of the spindle. Spindles are designed so that a clearance will always exist between spindle and minimum dimensional limit of the bore. This eliminates the possibility of jamming and marring the bore. It also minimizes wear and enables spindles to withstand from 10 to 40 times the engagements possible with conventional plug gages. Further, wear is automatically compensated through adjustment of the limit-indicating pointers whenever the gage is checked with the master setting rings.

An almost infinite variety of spindles, sleeves or rings, and snaps have been designed to permit checking internal and external diameters with air gages. In some cases several diameters and the bore depth are simultaneously checked by a multiple gage, having a flowmeter for each dimension to be verified. In all cases the spindle may either be attached directly to the gage assembly or be remote from the gage and connected through flexible tubing. Gages equipped with a remote spindle are practical for checking long bores, such as gun barrels, with ease and extreme accuracy.

ADJUSTMENT AND OPERATION OF AIR GAGES

All air gages are set to the required limits through the use of master setting rings or disks. The actual procedure will vary slightly with the make of gage—the principal difference being whether a float or a needle is used for indications.

In general the setting-up or adjustment procedure for internal diameters involves placing the gage in operation and first passing a maximum master setting ring over the spindle. The adjustable marker is set at the point to which the float (or needle) stabilizes. The same procedure is repeated with the minimum master ring, to set the second marker. Plus and minus tolerance limits are then established, and actual gaging may proceed. The float (or needle) will not reach the low-limit marker if the diameter is undersize, or it will pass beyond the high-limit marker if the diameter is oversize.

SEMIAUTOMATIC GAGES

Many machined parts require the checking of a quantity of diameters, and a number of gages would be required to accomplish all required inspection operations by conventional methods. Not only would a mass of equipment be required, but the labor cost would be proportionately high, as the part is checked by first one gage and then another. This condition has led to the development of semiautomatic multiple-dimension gages for simultaneous checking of several dimensions on high-production parts.

Multichek Gage

The Sheffield Multichek gage shown in Fig. 9:29 is one example of a semiautomatic multiple-dimension gage. Equipped with seven electric snap-gage heads permanently positioned in a rigid frame, this gage is capable of simultaneous checking of seven external diameters. If all diameters are within limits, the master light will glow and the inspector can accept the part without further dimensional investigation. If one or more dimensions are beyond limits, the master light will not glow, but a red light will be illuminated for each incorrect dimension.

This form of gage is ideal for high production of precision parts, but it is not economical when relatively few parts are to be checked on each shift. In these cases standard measuring instruments and gages should be used.

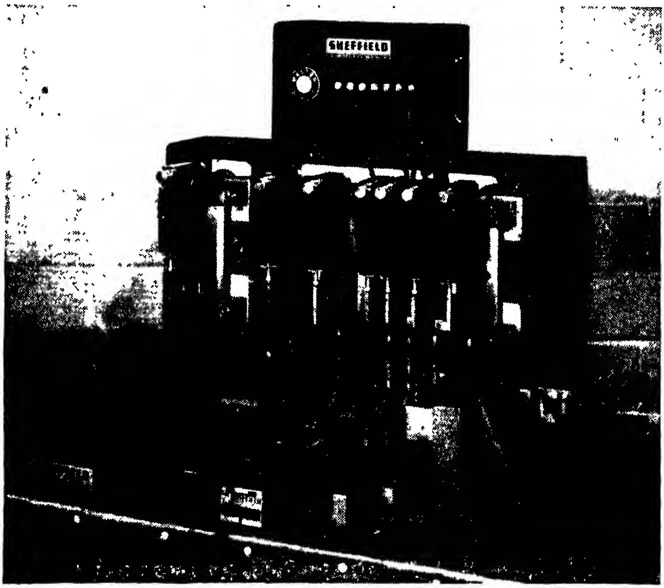


FIG. 9:29. Multichek semiautomatic multiple-dimension gage. (*Courtesy of The Sheffield Corporation.*)

PISTON-RING ELECTRONIC GAGE

The semiautomatic piston-ring electronic gage shown in Fig. 9:30 was designed by the Sheffield Corporation to check automatically the trueness of periphery and the width of gap of a specific size of piston ring. The gaging functions are performed by three scanning beams of light directed onto three photoelectric cells, which energize electronic circuits to illuminate three signal lights.

Each piston ring to be checked is inserted inside a master ring, and the master ring is placed on the instrument table, where it is rotated by a driving roller powered by an electric motor. As the master ring revolves, one beam of light is projected on the periphery of the piston ring. A clearance between master and

piston rings will reveal any out-of-round condition exceeding allowable limits. If the periphery is within limits, a green signal light will be illuminated at the end of one complete revolution, provided that the width of gap is also within tolerance. The gap width is checked by another photoelectric circuit, which will flash a yellow light if the gap width is undersize and indicates a reworkable ring. The red light is illuminated if the gap width is

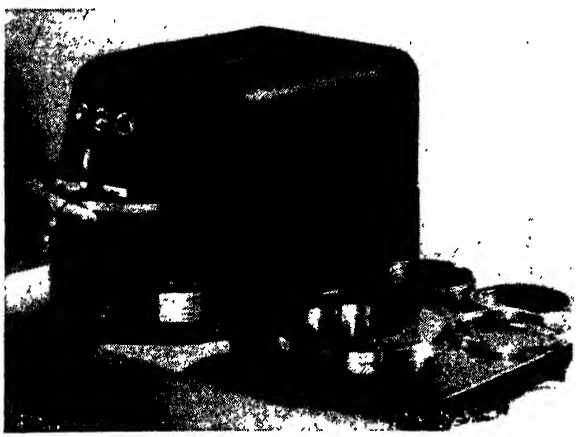


FIG. 9:30. Piston-ring electronic gage. (*Courtesy of The Sheffield Corporation.*)

oversize and indicates a ring that must be rejected. The lights remain illuminated until the master ring is removed from the gage.

AUTOMOTIVE CYLINDER-BLOCK GAGE

Automotive cylinder blocks present a complex inspection problem. Each cylinder bore must be held within close limits of diameter, taper, and out-of-roundness and must be classified into specified groups for selective assembly with pistons of matching diametral values. A semiautomatic multiple-dimension air gage for simultaneously gaging cylinder bore diameters at 32 points for go and not-go and proper classification, developed by the Sheffield Corporation for the Buick Division of General Motors, is shown in Fig. 9:31.

Each of eight cylinder bores is simultaneously checked at four points by this special Precisionaire gaging machine. Two of these machines are set in the production conveyor lines. Cylinder

blocks come off the conveyor onto a machine. A starting button actuates a hydraulic loading mechanism, which advances the block into gaging position, where two hydraulic plungers and a shot bolt firmly locate and hold the block aligned in position.

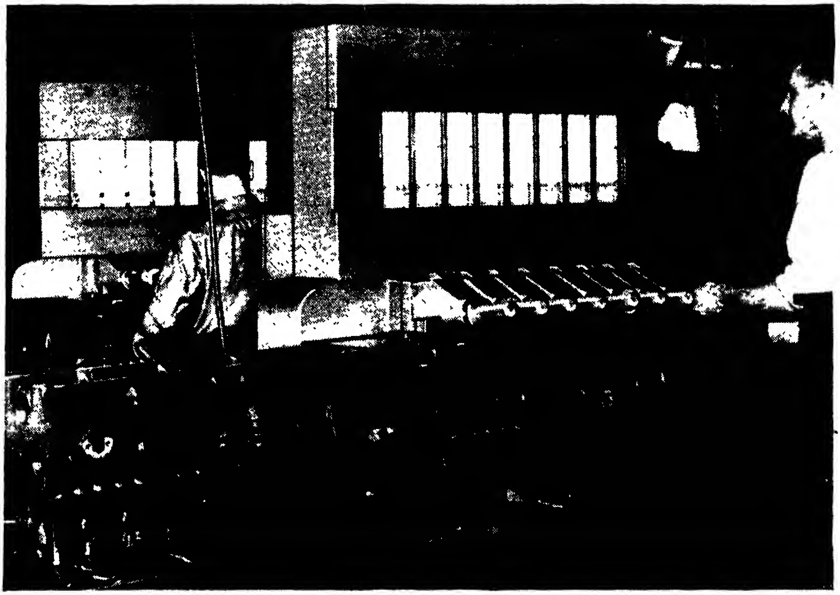


FIG. 9:31. Semiautomatic multiple-dimension air gaging machine for checking automotive cylinder blocks. (*Courtesy of The Sheffield Corporation.*)

Once the block is aligned, eight air-gaging assemblies of four spindles each automatically enter the cylinder bores, stopping at a predetermined point. The floats in the 32 flowmeter tubes fall simultaneously into position, indicating the dimensional accuracy at four points in each bore. Should interference be encountered during entrance of the gaging spindles, the machine is automatically stopped and a red light is illuminated, to indicate the faulty bore. An out-of-round check of any bore can be made by manually rotating the gaging spindles. Classification scales at the float tubes for each bore indicate the group number of the bore, which is then stamped on the block opposite each bore.

After all bores have been stamped, the gaging spindles are retracted. The machine is then ready to repeat the gaging cycle on the next block, which, as it comes into gaging position, shoves

the block just inspected onto a conveyor, which takes it away from the gaging machine.

THE AUTOMATIC SONIGAGE

The automatic Sonigage is a relatively simple ultrasonic instrument produced by the Magnaflux Corporation for specialized nondestructive tests of many materials. A feature of this instrument is that *only one surface need be available to measure thickness* with less than 2 per cent error. Thickness of tubes, as well as of flat parts, between 0.005 and 0.250 in., may be read directly; and up to several inches, may be read indirectly. Solid parts may

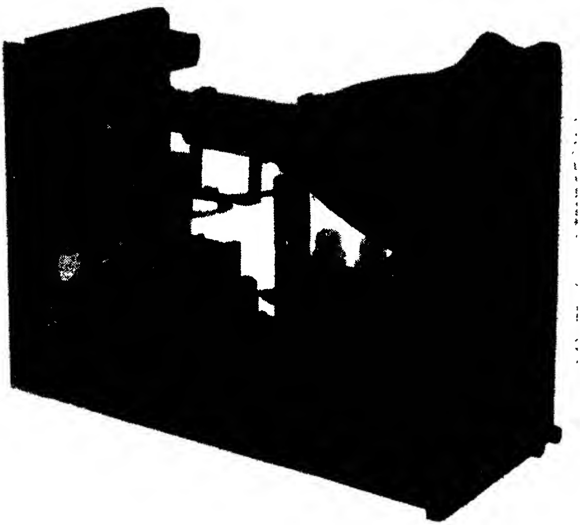


FIG. 9:32. View of the elements of the automatic Sonigage. All elements of the gage except crystal and cable are built into one cabinet. (*Courtesy of Magnaflux Corporation.*)

be inspected for freedom from flawed regions and for some types of defective bonds not readily located by other methods.

This instrument employs an electronic oscillator to generate electrical voltage, the frequency of which is continuously varied throughout the tuning range of the oscillator by a motor-driven tuning condenser. A cathode-ray oscilloscope provides a means to indicate the point or points at which the material being checked

resonates. Inasmuch as resonate frequency and thickness of the item are related for any given material, it is possible to calibrate the Sonigage to read thickness directly. Various ranges are obtained through use of different pickup crystals and calibration

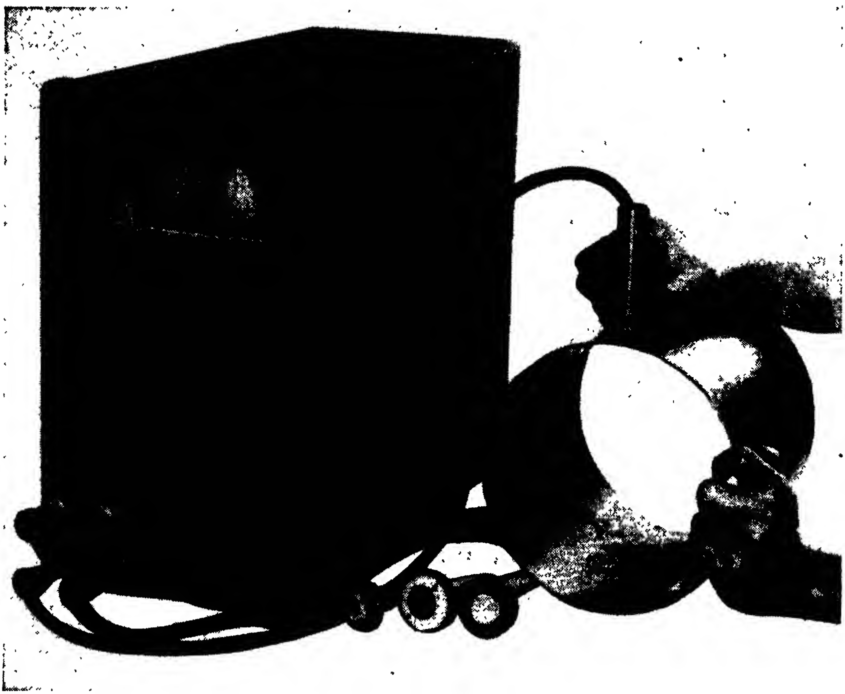


FIG. 9:33. Checking the thickness of a thin-wall cylinder with the Sonigage. (*Courtesy of Magnaflux Corporation.*)

scales. To facilitate changing, the scales are printed on transparent sheets, which are inserted in a slide holding them over the oscilloscope screen.

In addition to thickness determination of "blind" members that do not permit applying a gaging element to both surfaces, the Sonigage may be used to give information on the soundness of the part. Subsurface cracks, voids, and similar defects of castings, forgings, furnace-brazed parts, and cemented assemblies are revealed by the Sonigage, because the fault area has the effect of indicating a lesser thickness as the pickup crystal is moved over the surface to be checked.

CHAPTER 10

TEST EQUIPMENT

Inspection testing ranges from physical determination of tensile strength to X-ray investigation of hidden defects in castings. Practically all forms of physical and chemical testing that are normally used to determine the true condition of materials, parts, and assemblies may be involved. A majority of test work relates to receiving inspection and involves determining that received items meet all purchase order requirements. Additional testing may be required to ascertain hardness and soundness of fabricated parts, particularly those involving heat-treatment, machining, and welding. Other testing relates to operational inspection of assemblies and completed end items.

Equipment for direct tensile-strength tests and chemical analysis are ordinarily found only in extensive inspection departments. In a majority of cases these determinations are contracted to organizations specializing in physical and chemical testing. Operational testing, on the other hand, is unique to the product manufactured and must be established through experience to fit the particular quality needs.

This discussion of test equipment is limited to apparatus normally found in the inspection department of an organization that manufactures a moderately precise product. Hardness testers, magnetic-particle and fluorescent-penetrant inspection apparatus, and industrial X-ray inspection equipment are considered; these will accommodate a majority of standard tests required for precision inspection.

HARDNESS TESTING

A majority of manufactured articles involve parts having definite requirements for hardness and/or tensile strength. In every case in which these factors are involved there is need for a

Rockwell								Brinell		Psi
B	C	15-N	30-N	45-N	15-T	30-T	45-T	(1)	(2)	(3)
	80	96.5	92.0	87.0						
	79	....	91.5	86.5						
	78	96.0	91.0	85.5						
	77	....	90.5	84.5						
	76	95.5	90.0	83.5						
	75	....	89.0	82.5						
	74	95.0	88.5	81.5						
	73	....	88.0	80.5						
	72	94.5	87.0	79.5						
	71	....	86.5	78.5						
	70	94.0	86.0	77.5	....					
	69	93.5	85.0	76.5						
	68	....	84.5	75.5	....					
	67	93.0	83.5	74.5	....					
	66	92.5	83.0	73.0	....					
	65	92.0	82.0	72.0	....					
	64	....	81.0	71.0	....					
	63	91.5	80.0	70.0	....					
	62	91.0	79.0	69.0	....		.			
	61	90.5	78.5	67.5	....					
	60	90.0	77.5	66.5	....			614		314
	59	89.5	76.5	65.5	....		..	600		306
	58	....	75.5	64.0	....		.	587		299
	57	89.0	75.0	63.0	....		..	573		291
	56	88.5	74.0	62.0	....		..	560		284
	55	88.0	73.0	61.0	....		..	547		277
	54	87.5	72.0	59.5	....		...	534		270
	53	87.0	71.0	58.5	....		..	522		263
	52	86.5	70.5	57.5	....			509		256
	51	86.0	69.5	56.0	....		...	496		250
	50	85.5	68.5	55.0	....		..	484		243
	49	85.0	67.5	54.0	....		..	472		236
	48	84.5	66.5	52.5	....		...	460		230
	47	84.0	66.0	51.5	....		.	448		223
	46	83.5	65.0	50.0	....		...	437		217
	45	83.0	64.0	49.0	....		...	426		211
	44	82.5	63.0	48.0	....		...	415		205
	43	82.0	62.0	46.5	....		..	404		199
	42	81.5	61.5	45.5	....		.	393		194

Rockwell								Brinell	
B	C	15-N	30-N	45-N	15-T	30-T	45-T	(1)	(2)
79	..	....	....	....	....	69.5	52.0	147	128
78	..	....	....	....	86.0	69.0	51.0	144	126
77	.	....	....	....	85.5	68.0	50.0	141	124
76	..	....	....	....	....	67.5	49.0	139	122
75	..	....	....	....	85.0	67.0	48.5	137	120
74	.	....	....	....	....	66.0	47.5	135	118
73	..	....	....	....	84.5	65.5	46.5	132	116
72		....	....	....	84.0	65.0	45.5	130	114
71		....	....	....	....	64.0	44.5	127	112
70	.	....	....	....	83.5	63.5	43.5	125	110
69		....	....	....	83.0	62.5	42.5	123	109
68	.	....	....	....	....	62.0	41.5	121	107
67	.	....	....	....	82.5	61.5	40.5	119	106
66	..	....	....	....	82.0	60.5	39.5	117	104
65		....	....	....	....	60.0	38.5	116	102
64	..	....	....	....	81.5	59.5	37.5	114	101
63	..	....	....	....	81.0	58.5	36.5	112	99
62	..	....	....	....	....	58.0	35.5	110	98
61	..	....	....	....	80.5	57.0	34.5	108	96
60	.	....	....	....	....	56.5	33.5	107	95
59	.	....	....	....	80.0	56.0	32.0	106	94
58	.	....	....	....	79.5	55.0	31.0	104	92
57		....	....	....	....	54.5	30.0	103	91
56	..	....	....	....	79.0	54.0	29.0	101	90
55	..	....	....	....	78.5	53.0	28.0	100	89
54	.	....	....	....	....	52.5	27.0	...	87
53	..	....	....	....	78.0	51.5	26.0	...	86
52	.	....	....	....	77.5	51.0	25.0	...	85
51	..	....	....	....	....	50.5	24.0	...	84
50	..	....	....	....	77.0	49.5	23.0	..	83
49	..	....	....	....	76.5	49.0	22.0	...	82
48	..	....	....	....	....	48.5	20.5	..	81
47	..	....	....	....	76.0	47.5	19.5	...	80
46	.	....	....	....	75.5	47.0	18.5	...	..
45	..	....	....	....	....	46.0	17.5	..	79
44	..	....	....	....	75.0	45.5	16.5	...	78
43	..	....	....	....	74.5	45.0	15.5	...	77
42	.	....	....	....	....	44.0	14.5	...	76

	41	81.0	60.5	44.5	....	....	...	382	..	188
	40	80.5	59.5	43.0	....	..	....	372	.	182
	39	80.0	58.5	42.0	....	....	....	362	...	177
	38	79.5	57.5	41.0	....	....	....	352	..	171
	37	79.0	56.5	39.5	....	....	....	342	..	166
	36	78.5	56.0	38.5	....	....	....	332	...	162
	35	78.0	55.0	37.0	....	....	....	322	..	157
	34	77.0	54.0	36.0	....	....	..	313	..	153
	33	76.5	53.0	35.0	....	....	....	305	.	148
	32	76.0	52.0	33.5	....	....	...	297	...	144
	31	75.5	51.5	32.5	....	....	..	290		140
	30	75.0	50.5	31.5	....	...	....	283	.	136
	29	74.5	49.5	30.0	....	....	.	276	..	132
	28	74.0	48.5	29.0	....	....		270	..	129
	27	73.5	47.5	28.0	....	..		265	..	126
	26	72.5	47.0	26.5	....	....	.	260	..	123
	25	72.0	46.0	25.5	....	..		255	..	120
	24	71.5	45.0	24.0	....	.	..	250	...	117
	23	71.0	44.0	23.0	....	....	...	245		115
100	22	70.5	43.0	22.0	93.0	82.0	72.0	240	201	114
99	21	70.0	42.5	20.5	92.5	81.5	71.0	235	195	111
98	20	69.5	41.5	19.5	....	81.0	70.0	229	189	108
97	..	....	....	....	92.0	80.5	69.0	222	184	106
96	.	....	....	....	....	80.0	68.0	216	179	103
95		....	..	....	91.5	79.0	67.0	210	175	101
94	.	....	...	....	....	78.5	66.0	205	171	98
93		....	....	....	91.0	78.0	65.5	200	167	96
92	.	....	....	..	90.5	77.5	64.5	195	163	93
91		....	....	..	...	77.0	63.5	190	160	91
90		....	....	....	90.0	76.0	62.5	185	157	89
89	.	....	..	....	89.5	77.5	61.5	180	154	87
88		....	....	....	....	75.0	60.5	176	151	85
87	..	....	....	....	89.0	74.5	59.5	172	148	83
86	..	....	....	....	88.5	74.0	58.5	169	145	81
85	..	....	....	....	....	73.5	58.0	165	142	80
84	.	....	....	....	88.0	73.0	57.0	162	140	78
83	..	....	....	....	87.5	72.0	56.0	159	137	77
82	..	....	....	....	....	71.5	55.0	156	135	75
81	..	....	....	....	87.0	71.0	54.0	153	133	74
80	..	....	....	....	86.5	70.0	53.0	150	130	72

41		....	....	....	74.0	43.5	13.5	...	75
40	.	....	....	....	73.5	43.0	12.5		
39	.	....	....	....	....	42.0	11.0	...	74
38		....	....	....	73.0	41.5	10.0	...	73
37	..	....	....	....	72.5	40.5	9.0	...	72
36	..	....	....	....	....	40.0	8.0		
35	..	....	....	....	72.0	39.5	7.0	...	71
34	..	....	....	....	71.5	38.5	6.0	...	70
33	..	....	....	....	....	38.0	5.0	...	69
32	..	....	....	....	71.0	37.5	4.0		
31	..	....	....	....	....	36.5	3.0	...	68
30	.	....	....	....	70.5	36.0	2.0	...	67
29	.	....	....	....	70.0	35.5	1.0		
28	.	....	....	....	....	34.5	....	...	66
27	.	....	....	....	69.5	34.0			
26	.	....	....	....	69.0	33.0	....	...	65
25	.	....	....	....	....	32.5	....	..	64
24	..	...	....	...	68.5	32.0			
23		....	....	....	68.0	31.0	....	..	63
22	.	....	....	....	....	30.5	....	.	
21	.	....	....	....	67.5	29.5	....	...	62
20	.	....	...	....	....	29.0			
19	..	....	....	....	67.0	28.5	....	...	61
18		...	....	....	66.5	27.5			
17		....	....	....	....	27.0	....	..	60
16	.	....	....	....	66.0	26.0			
15	.	....	....	....	65.5	25.5	....	...	59
14		....	....	....	....	25.0			
13	.	....	....	...	65.0	24.0	....	...	58
12		....	....	....	64.5	23.5			
11	.	....	....	....	....	23.0			
10	.	....	....	....	64.0	22.0	....	...	57
9	.	....	....	....	....	21.5			
8	..	....	....	....	63.5	20.5			
7	..	....	....	....	63.0	20.0	....	...	56
6	..	....	....	....	....	19.5			
5	.	....	....	....	62.5	18.5	....	...	55
4	..	....	....	....	62.0	18.0			
3	.	....	....	....	....	17.0	....	...	...
2	..	....	....	....	61.5	16.5	....	...	54
1	..	....	....	....	61.0	16.0			
0	.	....	....	....	....	15.0	....	...	53

FIG. 10:1. Relationship of Rockwell and Brinell hardness indexes to tensile strength of alloy steels. *Note:* col. (1) 3,000-kg load; col. (2) 500-kg load; col. (3) tensile strength in thousand psi. Values below 72,000 psi are inexact, and may vary considerably with different steels.

hardness-testing machine in the inspection department. The hardness of steels bears a positive relationship to their tensile strength, and the hardness tester can be used to obtain quickly an *indirect* nondestructive determination of material strength—indirect, through determining hardness and comparing this with an index of equivalent tensile strength, but nonetheless accurate.

Several hardness-testing methods and corresponding indexes are in use. The Rockwell and Brinell systems are commonly used in this country. Both operate on the general principle of measuring and indicating penetration of the material upon application of a standardized pressure to a special penetrator point. The relationship of Rockwell and Brinell indications to tensile strength of alloy steels is shown in Fig. 10:1.

Both hardness and tensile-strength requirements are usually specified as a small range, such as a hardness of Rockwell C45–C50, or a tensile strength of 125–145,000 psi. To do otherwise would be impractical, for it is not feasible consistently to heat-treat metals to an *exact* hardness or tensile strength. On the other hand, production heat-treatment methods can readily produce materials that will consistently be within a small range of hardness or strength.

Tensile-strength requirements should not be specified as certain values on a hardness scale (such as Rockwell C35–C40 or Brinell 450), but always as the range in pounds per square inch that will be acceptable. To do otherwise may make mandatory the use of one certain form of hardness-testing machine by all concerned with inspecting the material, while a Rockwell, a Brinell, a Vickers, or some other standard machine can check the material with equal ease if the proper hardness-to-strength indexes are available.

THE ROCKWELL HARDNESS TESTER

The Wilson Mechanical Instrument Company's "Rockwell" hardness tester shown in Fig. 10:2 is typical of modern equipment used for this type of inspection determination. Each hardness number on the Rockwell scale is based upon the *additional* depth to which a penetrator is forced (into the material being tested) by a major load beyond the depth to which it first pene-

trated under a definite minor load. Without need of moving the item being tested, the minor load is first applied and quickly thereafter the major load is applied. The hardness number is automatically indicated on the instrument dial.

FIG. 10:2. Testing the hardness of a heat-treated steel bar with a Rockwell machine. (*Courtesy Wilson Mechanical Instrument Company.*)

The Rockwell hardness tester essentially consists of a sturdy C frame, supporting the anvil and the penetrator and enclosing the load-applying mechanism. The penetrator and the indicating instrument are contained in the head of the tester frame, while the adjustable anvil or table supporting the material being tested, together with the operating controls, is carried by the base of the frame.

Two Rockwell scales are normally used in testing,[1] designated as "Rockwell B" and "Rockwell C." The "B" scale is used for testing comparatively soft materials, such as unhardened steel, bronzes and brasses, cast iron, aluminum alloys, and other metals not extremely hard. A $\frac{1}{16}$-in.-diameter steel ball, mounted in a

[1] Special scales, such as "A," "E," and "F," are sometimes used for certain materials; such as the "E" and the "F" for testing aluminum-alloy forgings.

chuck to permit rapid replacement, is used as the penetrator in these cases and is applied with a 100-kg major load. Indications with the steel-ball penetrator are read on the red-lettered scale of the instrument dial and are designated as "B" scale readings.

Heat-treated steel and hard alloys of other metals are tested with a diamond-point (known as a "Brale") penetrator, applied with a 150-kg major load. These indications are read on the black-lettered scale of the instrument dial, which provides for readings of Rockwell C–10 to C–100.

The indicator for the Rockwell hardness tester (see Fig. 10:3) is a precision measuring instrument specially designed for this

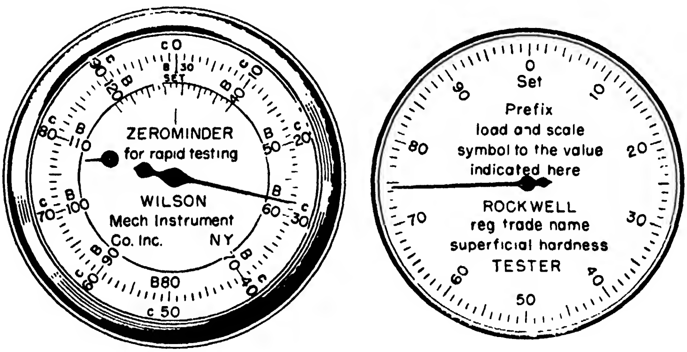


FIG. 10:3. Rockwell tester dials for standard and superficial hardness machines. (*Courtesy Wilson Mechanical Instrument Company.*)

application. The "zerominder" scale, shown at the top of the central part of the standard machine dial, is intended to reduce operating time during testing by providing for zeroizing of the indicator during application of the major load. It is provided for those who wish to use it and does not interfere with the normal manner of zero setting.

Conventional zeroizing, used by earlier Rockwell machines, requires that—prior to applying the major load—the bezel rim of the dial be turned to register the CO-Set-B30 line with the long pointer. When the zerominder is used, this is done after applying the major load, through use of the zero-adjuster on the anvil jackscrew.

Operation of the Rockwell machine is relatively simple when

the zerominder is used, involving the following basic steps, identified by the sequence numbers in Fig. 10:4.

Material to be tested is placed securely upon the anvil (1) and then elevated into contact with the penetrator by revolving the jackscrew control wheel (2). Additional pressure is applied with the jackscrew until the small pointer of the indicating instrument is nearly vertical and slightly to the right of the index dot, and pressure is continued until the long pointer is approximately vertically upward. The exact position of the long pointer on the fixed zerominder scale (3) is noted. The depressor bar (4) is now tapped downward to apply the major load. Following this, the knurled ring (zero adjuster) is rotated (5) until the set-line on the movable instrument scale registers at the identical zerominder-scale position noted prior to application of the major load. As soon as the long pointer comes to rest, the crank handle (6) is pulled forward to release the major load but leave the minor load still applied. The Rockwell hardness number can now be read directly from the instrument scale.

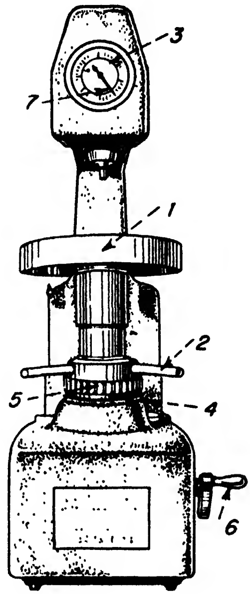


Fig. 10:4. Sequence of operations when using Rockwell hardness tester with "zerominder" for routine inspection tests. (*Courtesy Wilson Mechanical Instrument Company.*)

To conform to custom, large Rockwell hardness numbers indicate shallow indention and hard material, while small numbers indicate soft material. The greatest hardness of material that can be tested is limited only by the ability of the diamond-point penetrator to withstand the stress.

Rockwell Tests of Metal Shapes and Sheet Stock

The preceding discussion of Rockwell testing was predicated upon examination of reasonably heavy metal sections with substantial flats for application of anvil and penetrator. Other metal shapes, such as rod, tubing, and thin sheet, can be tested with equal ease, provided that reasonable precaution is exercised and

that a suitable vee block is used for testing round shapes.

Round sections may be tested in the conventional manner and, except for very soft material, there seems to be no great difference in the readings on flat material and material with a ½-in. radius. When the material surface will permit and when extremely accurate readings are required, it is sometimes advisable to grind a very small flat on the surface of the round section, to provide a test area.

FIG. 10:5. Using an offset penetrator to determine Rockwell hardness of inner surface of a ring. (*Courtesy Wilson Mechanical Instrument Company.*)

Tubing may be tested like solid rounds unless the material is quite soft, the wall very thin, or the diameter of the tube large in proportion to its wall thickness. Any of these conditions will result in deflection upon application of the major load and, therefore, in correspondingly erroneous readings. In such cases it may be necessary to provide a close-fitting mandril, for insertion in the tube during testing. Inner surfaces of tubing or rings may be tested by using the offset penetrator shown in Fig. 10:5.

In the case of *sheet stock* it must be taken into account that the depth of impression of the penetrator (and consequently, the Rockwell reading) depends partly upon the hardness of the material penetrated and partly upon the hardness of the material considerably below the actual impression. Therefore, it is apparent that in testing thin sheet metal there is insufficient material to provide normal resistance to indention. If the metal is thin enough to register a compression mark or to cause protrusion on the opposite side, the reading will not be the true Rockwell value and it represents only a comparison with other metal of the same thickness. A similar error will be en-

countered if the penetrator is applied too close to the edge of thin material.

Rockwell Superficial Hardness Tester

A superficial hardness tester can be used where it is essential that the test indention be extremely minute. This tester is especially valuable in cases where the material is very thin or where marring of the surface must be reduced to a minimum. Instances of its normal application are for testing the hardness of razor blades and various surfaces where the indention must subsequently be ground or lapped away.

The Rockwell superficial hardness tester operates on exactly the same principle as the regular Rockwell machine, except that much lighter major and minor loads are used and the depth-measuring system is much more sensitive. A minor load of 3 kg, and major loads of 15, 30, and 45 kg are used. A penetration of about 0.001 in. is normal for the superficial machine when testing hardened tool steel with a 30-kg major load, in contrast to a penetration of about 0.0035 in. in identical material with the standard tester.

Hardness measurements obtained with the superficial tester are indicated on an instrument dial similar to that of the standard machine, but the dial markings and the hardness-designation scheme are different. Superficial hardness designations comprise three parts: major load in kilograms, type of penetrator used, and dial reading. Thus a designation of Rockwell 30–N45 indicates a test made with a major load of 30 kg, employing a diamond-point penetrator and registering a dial reading of 45 points. When the $\frac{1}{16}$-in. ball penetrator is used, the letter "T" is substituted for "N" in the hardness designation.

The superficial hardness designations bear a direct relationship to the standard Rockwell B and C scales, as shown in the graphs in Fig. 10:6.

Material to be tested on the Rockwell superficial hardness machine should be smoothly finished but need not be polished. There must be no dust, no scale, nor any particles on the under surface of the specimen or on the anvil; for any sinking of the material under testing load will be added to the actual penetration con-

trolling the dial reading. Operation of this instrument involves precision micrometric measurements, and requires more care than is demanded for operation of the standard machine.

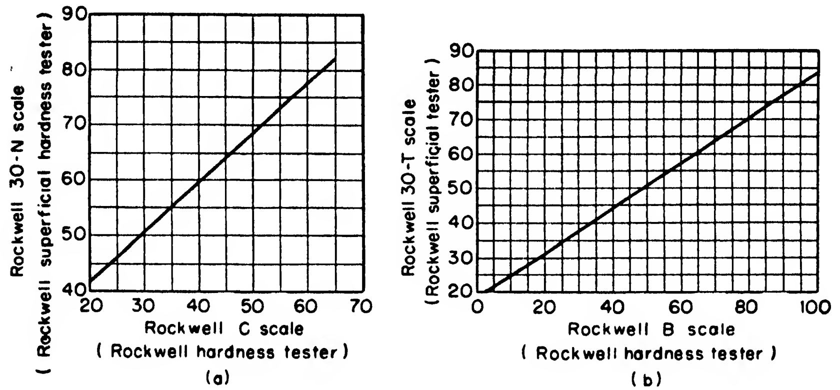


FIG. 10:6. Approximate relationships of superficial hardness to standard Rockwell designations. (*a*) Indicates relationship of Rockwell 30-N and C scales; (*b*) indicates relationship of Rockwell 30-T and B scales. (*Courtesy Wilson Mechanical Instrument Company.*)

Accessories available for the superficial tester are similar to those provided for the standard Rockwell machine. Vee and roller anvils are available for testing cylindrical objects, and offset penetrators can be obtained for testing the inner surface of rings and tubes.

Test disks, which are available for all Rockwell scales, provide a means of readily checking the accuracy of the hardness tester. These are a necessity wherever Rockwell machines are used and should be maintained by the group responsible for gage and instrument control.

OTHER HARDNESS TESTERS

While it is probable that the Rockwell hardness tester will be encountered most frequently in precision inspection work, there are a number of other equally accurate hardness testers. Some, like the Brinell, are adaptable to testing a wide variety of materials. Others, such as the Shore Durometer, are intended only for testing certain materials.

Brinell Hardness Tester

The Brinell hardness tester essentially comprises a heavy C-frame having in its base a jackscrew for elevating an anvil to support the work and in its head a penetrator spindle, provided with a means of loading to definite pressure. The material to be tested (work) is placed on the anvil and raised to contact the steel-ball penetrator. A hydraulic pump is operated to apply the proper load,[2] as indicated by a pressure gage on the tester.

The load causes the penetrator to sink into the material for a distance proportional to the hardness of the work. After penetration, the Brinell hardness number is determined by measuring the diameter of the indention by means of a special calibrated microscope. This reading may be translated into tensile strength by comparing it with the proper index for the material tested (see Fig. 10:1).

It should be noted that Brinell readings are based upon the penetration resulting from application of a single load, in contrast to the Rockwell system, wherein the hardness determination is based upon the increment of penetration obtained by applying an additional load after first preloading the work. This basic difference introduces greater possibility of error when Brinell machines are handled by inexperienced operators, as greater care must be taken to insure that the surface tested is thoroughly clean, free from scale, flat, and fairly smooth.

The Scleroscope

The Scleroscope is a rebound-type hardness tester. It operates on the principle that a ball of given hardness, dropped from a definite height on various materials, will rebound higher from hard material than from soft. The original form of this instrument comprises a graduated glass tube containing a diamond-hard ball, with means of dropping the ball on the work from a definite height. The height of the rebound, which is read on graduations of the glass tube, provides the hardness number of the specimen.

[2] Different loads are used for ferrous and nonferrous materials.

Production-inspection versions of the Scleroscope are available with a dial indicator, to show the hardness number. This eliminates the possibility of error through reading the wrong graduation at the top of the rebound.

Tukon Tester for Knoop Hardness Numbers

The Tukon tester is a comparatively new hardness tester (see Fig. 10:7), operating on the Knoop Indenter principle invented

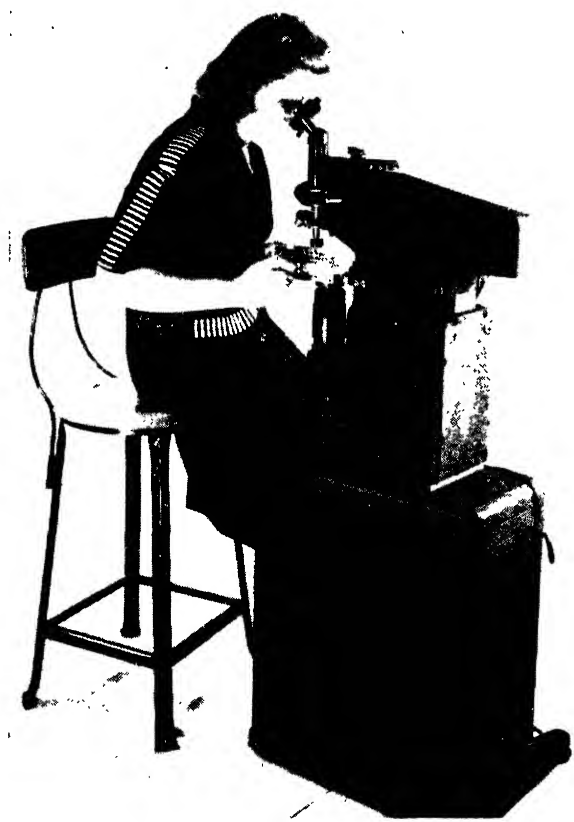


Fig. 10:7. Tukon Tester for Knoop hardness numbers. (*Courtesy Wilson Mechanical Instrument Company.*)

by Frederick Knoop of the National Bureau of Standards. It is an ultraprecision hardness-measuring instrument, using very light testing loads and producing comparatively small indentions in

the work. Testing loads range from 25 to 3,600 *grams,* and the depth is measured in microns.

The Knoop indenter is a diamond point, ground into a pyramidal form that produces an elongated diamond-shaped indention having long and narrow dimensions of approximately the ratio of 7 to 1. The sides of the indenter point are ground to a wedgelike form, with a 172½-deg angle on the long dimension, and a 130-deg angle between the faces producing the narrow dimension of the indention.

This tester permits hardness determinations of extremely thin metal, plated surfaces, exceptionally hard and brittle metallic and nonmetallic materials, very shallow carburized or nitrided surfaces, or of any other work for which the applied load must be low and the indention extremely shallow to avoid injury to the tested surface.

The Tukon tester is fully automatic under electronic control in a synchronous cycle. The work to be tested is placed in a special micrometer stage having two-way horizontal adjustment. The indention is made by elevating the work against the Knoop Indenter, until the work's hardness resists further indention. As this condition is reached, elevation of the work automatically ceases, the load remains applied for a definite time, and then the work is automatically lowered, to clear the indenter. The work is then ready to be moved forward under the micrometer measuring microscope for determining the length of the indention's long dimension. The Knoop hardness number corresponding to the measured length for a given load is determined from a table supplied with the tester.

Shore Durometer

The Shore Durometer is used to determine the hardness of rubber, synthetic rubber, plastics, and similar materials. This instrument functions by measuring the movement of a spring-loaded pin of definite diameter when it is forced against the material to be tested. The pin is linked to a needle arranged to register with a hardness scale. As the pin pressure is always identical, the travel of the pin into the work is proportional to the hardness of the substance tested. Upon the pressure's being

balanced by the compressive resistance of the work, the pin travel ceases and the corresponding Durometer hardness is shown on the scale.

MAGNETIC-PARTICLE INSPECTION

When the failure of a part may be extremely costly, it is customary either to design with an excessive load factor or to inspect the part with exceptional care. The latter method is normally used for applications in which the weight of the part must be kept to the practicable minimum, as is the case with nearly all high-speed transportation equipment.

The magnetic-particle method of nondestructive testing has been developed to provide a rapid, economical means of checking magnetic materials for hidden defects, such as microscopic cracks that might result in fatigue failures in service. The testing of ferrous material by the magnetic-particle method consists essentially of magnetizing the work under test by means of a coil or by passing current directly through the part and applying an indicating medium, which is usually a suspension of finely divided magnetic material in a light oil, such as kerosene.

If there is a crack or a discontinuity in the work, the magnetic-leakage field formed across the crack (see Fig. 10:8) will attract the magnetic particles suspended in the oil, and an outline of the crack, greatly magnified, will be formed. If the indicating medium is applied while the work is being magnetized, the process is called the "continuous" method. When the indicator is applied after the work has been magnetized, the process is called the "residual" method.

Of the two methods of magnetization—using a coil or passing current directly through the work—each reveals a characteristic type of defect. Coil, or "longitudinal," magnetization establishes a field that reveals defects transverse to the axis of the work. Passing current through the work along its axis, known as "circular" magnetization, reveals defects running lengthwise of the work, such as a seam. With certain production parts, wherein experience has shown that only one type of defect will be encountered, it may be feasible to use only one type of magnetization. In many cases, however, it is best to subject all parts re-

quiring magnetic inspection to both types of magnetization. A demagnetization step normally is required between successive tests.

Magnetic determination of defects is not necessarily limited to faults that begin on the surface of the work. Defects just below

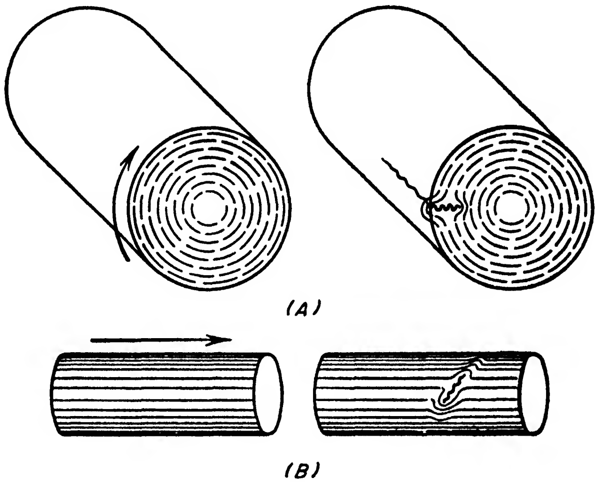


FIG. 10:8. (*A*) Magnetic paths in steel rod with and without defect when subjected to circular magnetization. (*B*) Paths in steel rod with longitudinal magnetization.

the surface, such as sand inclusions and subsurface porosity in steel castings, will cause sufficient disruption of the magnetic field to become evident during testing.

The wet, continuous method of magnetic inspection is satisfactory for a majority of magnetic inspections, but it is not the ultimate in sensitivity when deep-seated discontinuities are sought, as in weld and casting inspection. The best and most easily recognized patterns are produced with dry powder, largely because the shape of the dry particles tends to favor stringing or chaining. The dry-powder method is, therefore, preferable when the utmost in sensitivity is required.

MAGNAFLUX MAGNETIC TESTING EQUIPMENT

A variety of magnetic-particle inspection equipment is produced by the Magnaflux Corporation. Equipment of the general-

purpose type, illustrated in Fig. 2:2, is widely used in modern industry. Special-purpose, high-speed Magnaflux machines have been designed to meet the demand of increased speed of inspection when thousands of small parts of similar size and shape are involved. These are automatic or, at least, semiautomatic in operation.

Small portable Magnaflux units are used in overhaul and maintenance work where primary interest lies in the location of fatigue cracks. Since these are surface cracks, alternating-current magnetization is used to a very wide extent. The unit shown in Fig. 10:9 provides high-amperage alternating current, which may

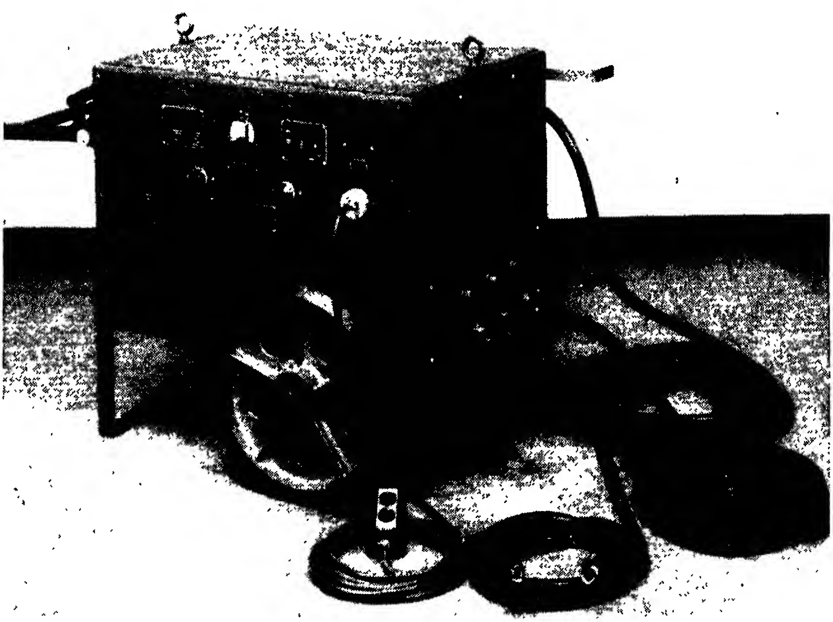


FIG. 10:9. Portable alternating-current magnetic inspection unit. (*Courtesy Magnaflux Corporation.*)

be applied either with prods, to obtain local magnetization, or by flexible cables formed into coils, to magnetize large areas.

These portable Magnaflux units find their most useful application in fields where the size of the items prohibits placing the work in a conventional machine. Railroad equipment and large welded-

steel tubular structures are examples of items suited to the use of portable magnetic-particle inspection equipment.

FLUORESCENT-PENETRANT INSPECTION

The magnetic-particle inspection method provides a practicable means for rapid investigation of ferrous materials for the presence of small surface and subsurface defects not apparent to visual inspection. This leaves a host of nonferrous materials that must be inspected by another method to detect "hidden" defects.

Inspection of nonferrous materials can be accomplished by the fluorescent-penetrant method. Fluorescence is a term used to describe the effects produced by certain chemicals that exhibit the peculiar property of emitting visible light from within themselves when exposed to near-ultraviolet light in the range between 3,200 and 4,000 angstrom units wave length. This type of "light," which is unseen by the human eye and is completely harmless to eyes and skin, is commonly known as "black light." Although this method can also be used to inspect for defects in ferrous materials, it is particularly suited to nonferrous articles.

Zyglo Fluorescent-penetrant Process

The Zyglo fluorescent-penetrant inspection method is one of the group of nondestructive testing methods developed by the Magnaflux Corporation. By means of a highly fluorescent liquid penetrant, "fluid light" can be flowed into the surface discontinuities of the work. Dipping the work into Zyglo penetrant permits entry of the fluorescent liquid into defects. After the fluorescent dip, a suitable period for penetration, removal of the penetrant that remains on the surface, and treatment with a developer to draw the penetrant to the surface of defects, the part is examined under "black light."

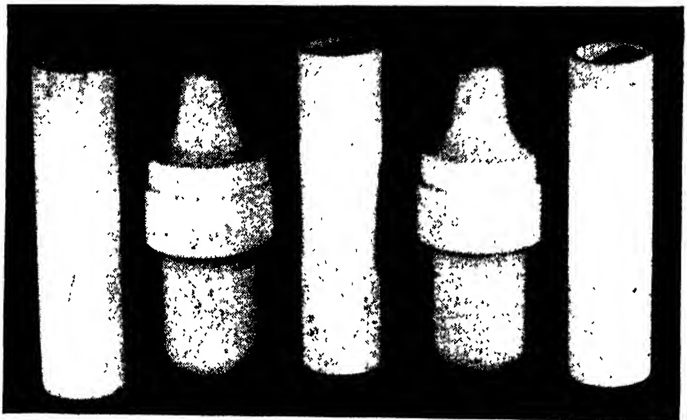
With all other light subdued, the near ultraviolet activates the Zyglo fluid wherever it has penetrated. Discontinuities fluoresce in brilliant contrast to the flawless surface from which the penetrant was rinsed. All cracks, holes, and seams emit visible light.

A unit for production inspection by the Zyglo process is shown in Fig. 10:10. Items are dipped into the penetrant at the extreme left of the illustration. This is followed by washing (left center)

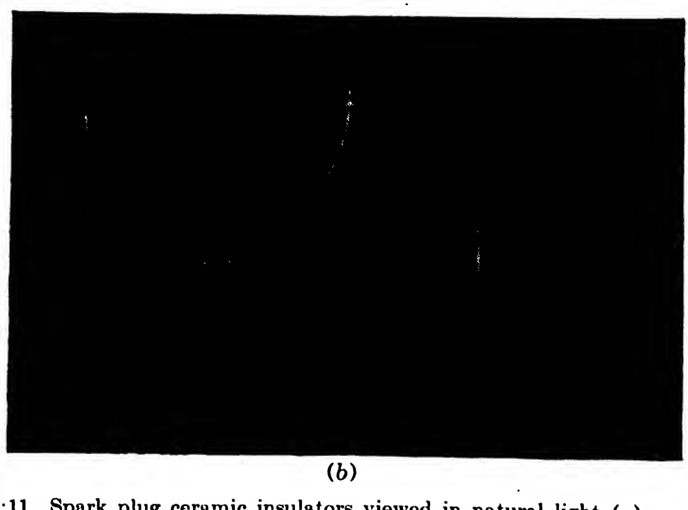
FIG. 10:10. Zyglo fluorescent-penetrant production-inspection unit. (*Courtesy Magnaflux Corporation.*)

with water spray to remove penetrant from their surfaces. Items are dried in the cabinet at the center of the Zyglo unit, and application of developer follows. Inspection takes place under "black light" in the hood at the extreme right of the unit. This unit requires manual handling of the items when they are transferred from one step to the next. Conveyorized units are used in high-production inspection, to eliminate the handling expense.

The effectiveness of Zyglo indications is demonstrated in the views, in Fig. 10:11, of ceramic insulators for spark plugs. When



(a)



(b)

FIG. 10:11. Spark plug ceramic insulators viewed in natural light (a), and under black light (b) after application of Zyglo penetrant. (*Courtesy Magnaflux Corporation.*)

viewed in natural light, the items appear to be flawless; but when they are examined under black light after Zyglo treatment, they are seen to contain many defects.

Equally striking results are obtained when the Zyglo process is

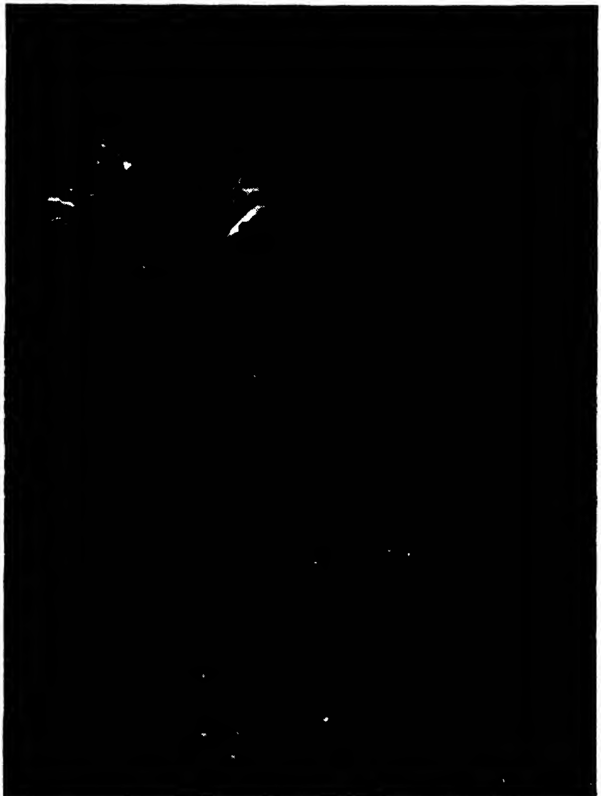


FIG. 10:12. Zyglo indication of defects in aluminum alloy casting. (*Courtesy Magnaflux Corporation.*)

used for inspection on nonferrous metals. This is shown in Fig. 10:12, where defects in an aluminum-alloy casting are revealed by the Zyglo process.

The Magnaglo Process

The Magnaglo process, developed by the Magnaflux Corporation, is a combination of magnetic-particle and fluorescent-penetrant inspection methods, which provides a more effective and

faster method of checking ferrous materials for hidden defects.

Magnaglo employs a special magnetic-particle paste, made for use with the wet method. This paste is mixed with a suitable oil (similar to kerosene) to form a suspension of fluorescent, ferromagnetic particles. A suitable magnetic field is induced in the part to be inspected. Sudden interruptions of this magnetic field

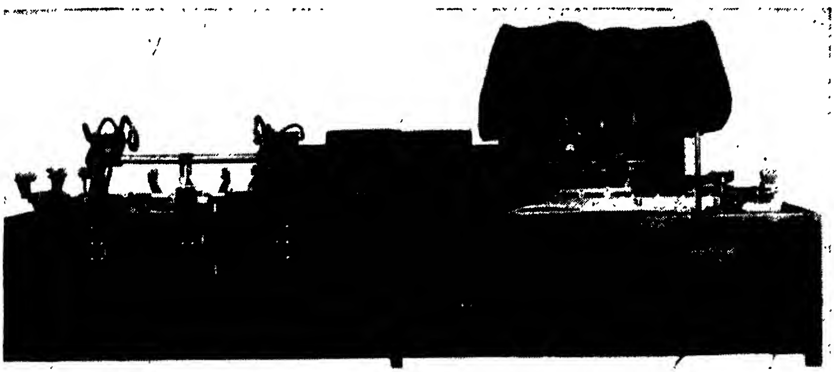


FIG. 10:13. Special Magnaglo unit for handling small crankshafts. Magnetizing and penetrant application are accomplished at the left side, and inspection under black light at the right. (*Courtesy Magnaflux Corporation.*)

by discontinuities in the work attract and hold the Magnaglo particles, thus forming definite indications of the location, extent, and shape of defects.

The Magnaglo penetrant is applied in the same manner as the regular magnetic-particle liquid employed with the wet Magnaflux process. The only difference is that the work is examined in a darkened enclosure under black-light illumination after removal from the magnetizing source. Indications appear as bright greenish-yellow lines of fluorescence, presenting greatly improved contrast of the indications against the background of the work.

Magnaglo is particularly effective on threaded and irregular shapes, removing all doubt regarding the validity of indications. Other applications include inspection of critical aircraft, bus, and truck parts during overhaul, when Magnaglo often reveals fatigue cracks that might pass unobserved under other methods

of examination. Minute cracks in tools, caused by improper grinding (see Fig. 10:14), heat-treatment, or careless handling, are readily revealed.

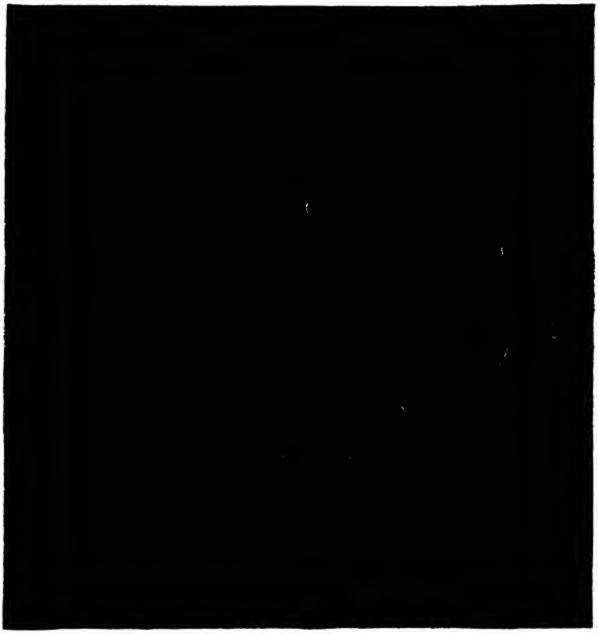


FIG. 10:14. Magnaglo indications of grinding cracks in finished part. (*Courtesy Magnaflux Corporation.*)

STATIFLUX PROCESS FOR NONMETALLICS

Nondestructive tests of a variety of nonconducting solids, such as ceramics, glass, porcelain-enameled products, and vitreous materials, can be carried out by the *electrostatic particle testing* process. Equipment for this process is manufactured by the Magnaflux Corporation under the trade name of Statiflux. Discontinuities, such as visible and nonvisible cracks and porosity, are readily indicated by this process.

Work to be inspected by the Statiflux process is dipped into a tank of hot penetrant solution at the left of the test unit (see Fig. 10:15), then placed on a rack for drainage. The surface is next dried by a brief application of an air jet or by wiping with cloths.

Electrostatically charged powder particles are blown over the prepared work with a special air gun (see Fig. 10:16). The particles are drawn to and held at the discontinuities (cracks,

FIG. 10:15. Statiflux unit for production inspection by the electrostatic-particle process. (*Courtesy Magnaflux Corporation.*)

scratches, porosity, and the like) by electrostatic leakage fields, while being repelled on the remainder of the surface. A heavy powder build-up results, to locate and mark each discontinuity (see Fig. 10:17).

The penetrant is an aqueous solution, harmless to nonmetallic substances, to operator, and to food products. The powder is an equally harmless material—available in colors to contrast with various backgrounds—which takes and holds a high electrostatic charge when blown from the air gun.

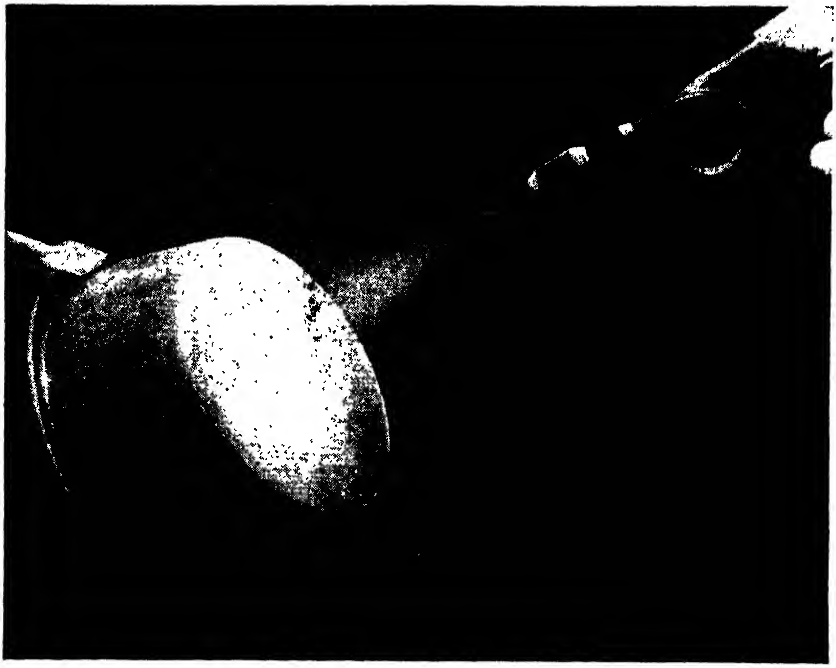


FIG. 10:16. Statiflux special air gun blows electrostatically charged powder onto the surface to be inspected. (*Courtesy Magnaflux Corporation.*)

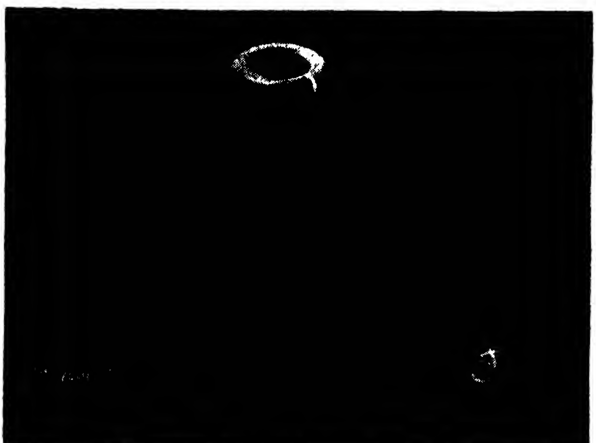


FIG. 10:17. Bottles inspected in high volume by electrostatic-particle process to locate typical rim cracks. (*Courtesy Magnaflux Corporation.*)

Defects can be located that are far below visible size and that would otherwise require microscopic examination for their detection. All defects located must be open to some surface, but this need not be the surface inspected, as they can be located if open only to the "back" surface.

INDUSTRIAL X-RAY INSPECTION

Industrial X-ray inspection (technically known as industrial radiography) is another means of nondestructive testing for hidden defects in materials and parts. Flaws located too far below the surface to be readily revealed by other testing methods are immediately apparent when inspected by X-ray. Porosity and shrinkage voids in castings are examples of defects commonly inspected with industrial X-ray methods.

The basic process of X-ray inspection is simply one of placing the work in close proximity to a sheet of X-ray film, situated between film and source of radiation, and then exposing the work to a properly timed radiation. The shadow of the work appears on the developed film, and any discontinuities in the work are immediately apparent.

Commercial X-ray Equipment

The Productograph (see Fig. 10:20) is an industrial X-ray unit designed for mass inspection of quantities of manufactured items when critical but rapid examinations are required. It is a self-contained unit and provides full protection of personnel against deleterious radiation without the use of a special room or additional equipment. This unit is used in conjunction with an industrial X-ray generator and control.

Operation of the Productograph is semiautomatic. Kilovoltage, milliampere, and on-off controls are in the main board on the X-ray generator. These are set to the required values to energize the X-ray unit. With the doors on the Productograph open, a timer in the auxiliary control board on the front of the unit is adjusted to the desired timing range (adjustable from 10 to 120 sec., in 2-sec. increments), and the control switch is set to automatic.

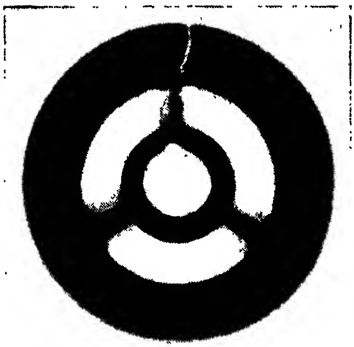


FIG. 10:18. Radiograph showing defects in pulley casting. (*Courtesy Westinghouse Electric Corporation.*)

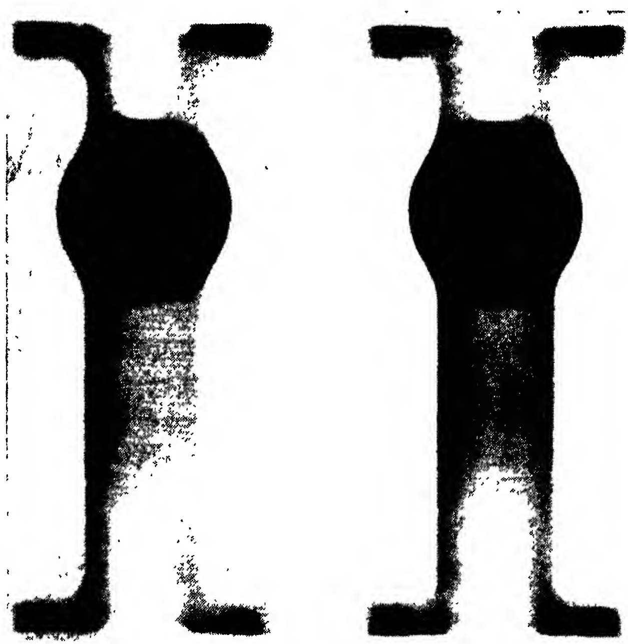


FIG. 10:19. Radiograph of two bracket castings. Note defects in casting at left. (*Courtesy Westinghouse Electric Corporation.*)

The items to be photographed are then placed on the dolly, and a cassette loaded with X-ray film is placed beneath the items. The dolly is then rolled through the open door to a centered position beneath the X-ray beam. The starting button on the X-ray hood is then pressed, closing the doors of the rayproof enclosure and starting the exposure. Upon the exposure's being completed,

FIG. 10:20. Productograph industrial X-ray unit (*Courtesy Westinghouse Electric Corporation.*)

the X-ray beam is shut off and the door is automatically opened. The dolly supporting the items is removed, and another loaded dolly is rolled into place for the next photograph.

An unshielded jib-crane type of industrial X-ray unit is shown in Fig. 10:21. This is used for installations in which the size of the work makes the horizontal and vertical travels of a standard

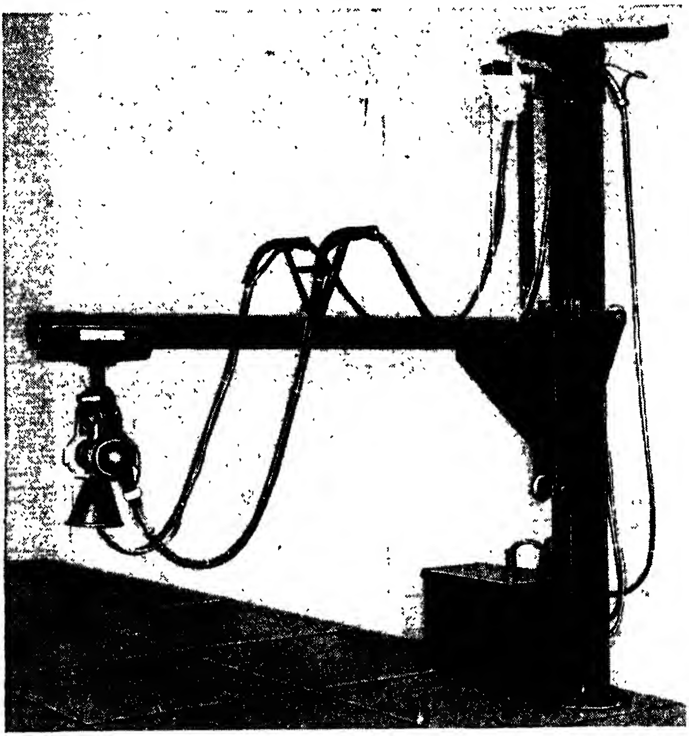


FIG. 10:21. A 250-kv industrial X-ray unit mounted on a jib-crane tube stand. (*Courtesy Westinghouse Electric Corporation.*)

tube-stand support inadequate. The vertical column on the unit shown is 14 ft high, and the boom radius is $14\frac{1}{2}$ ft.

The X-ray equipment shown in Fig. 10:22 is a Micronex unit for radiography, with exposure times of one-millionth of a second. This ultrahigh-speed unit is intended for application in radiographing fast-moving objects while they are in motion, the exposure time being so short that all motion is effectively arrested.

This unit is primarily intended for industrial and medical research. The exposure time of one microsecond is of such short duration that radiographs may be taken of the passage of a bullet through a gun barrel, to determine orientation or position of the missile at any predetermined or desired place along its path of travel or at the point of contact. Other interesting applications are high-speed radiographs to study impact reaction when a golf

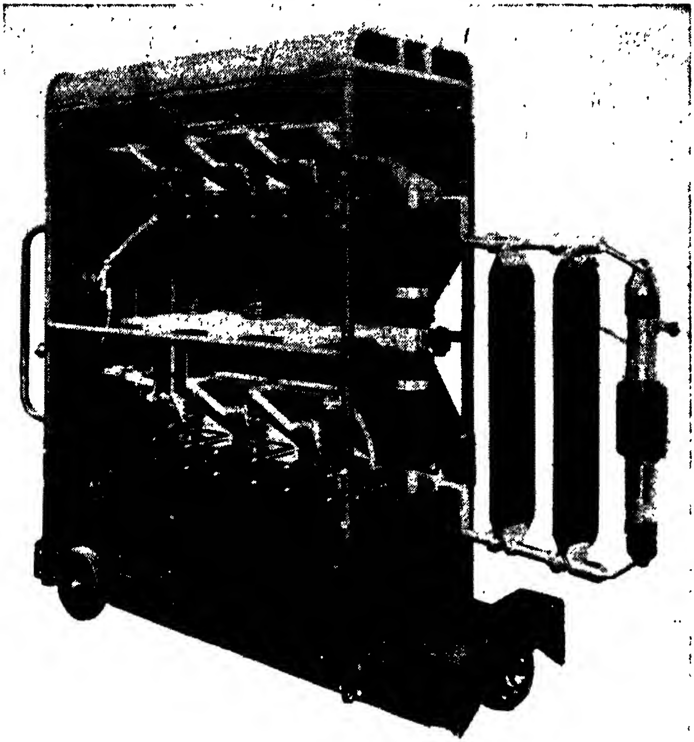


FIG. 10:22. Micronex ultrahigh-speed industrial X-ray unit. (*Courtesy Westinghouse Electric Corporation.*)

club strikes the ball, and the behavior of life under supersonic speeds and stratosphere altitudes.

It is unlikely that the Micronex will often be encountered in inspection work, although it offers interesting possibilities for examination of critical items while they are subjected to dynamic loads. However, it does demonstrate the flexibility and adaptability of the radiographic testing process.

CHAPTER 11
RECEIVING

Receiving inspection has the basic function of controlling the quality of all material purchased by the company. This is accomplished through examination of all received items, to determine conformance to applicable purchase orders.

Following inspection of a given shipment, an inspection receiving report must be issued, stating what conditions have been found and what quantities have been received, accepted, and rejected. This is forwarded through the receiving department to the material control and purchasing functions, and it becomes authority for payment to the vendor supplying the items that comprise the shipment.

It is a normal rule in business operations that only shipments authorized by a purchase order can be accepted by the receiving department. On this basis, the purchase order becomes the basic instrument for operation of the receiving function and, when properly processed, can also serve as the inspection receiving report.

Each purchase order provides complete information on what *should* be received in a given shipment. It is only necessary for Inspection to indicate on a copy of the order their findings regarding the corresponding shipment, and an adequate receiving report is created.

RECEIVING INSPECTION FUNCTIONS

The normal functions of receiving inspection include (A) responsibility for determining acceptability of (1) raw-stock material purchased from vendors; (2) parts and assemblies purchased from vendors; (3) parts and assemblies manufactured by outside production sources; (4) items which have been withdrawn from stores but not used and which require reinspection before

being returned to stores; (5) items which have been previously accepted but which, because of engineering changes, must be withdrawn from stores and reinspected, to determine current usability; and (B) magnetic-particle, fluorescent-penetrant, and X-ray inspection of all items requiring these examinations, whether as a receiving or a production operation.

While the basic function of receiving inspection involves examination of all purchased material upon arrival at the company's receiving department, there are additional responsibilities normally assigned to receiving inspection in the interest of reducing costs through consolidation of similar functions. For instance, it is customary for receiving inspection to accomplish all magnetic-particle inspection, on the basis that, while magnetic-inspection equipment is primarily needed for receiving inspection, this need may not require full-time operation. Magnetic inspection required during or following fabrication and assembly operations also can be routed through receiving inspection, to obtain full utilization of the equipment and avoid additional cost for duplicate equipment and personnel.

Receiving Inspection may be responsible also for performance testing all items that require special tests (such as hydraulic valves or electric motors), whether as a receiving or a production operation. In other cases this may be the duty of the inspection laboratory or of a production-process control group.

In each case of receiving inspection examination there are three possible courses of action that can be followed when disposition of the shipment is being made. Items meeting all relevant specifications are accepted and identified with an Inspection acceptance stamp, and the receiving records are posted to show acceptance.

Items which fail to meet requirements but which appear capable of rework are rejected and withheld by Receiving Inspection, and all interested parties are notified regarding Inspection's recommended rework procedure. In such cases, in contrast to production inspection procedure, the rework action is not initiated by Inspection but, instead, only a recommendation for rework is made. Additional factors, such as whether the rework should be accomplished by the company or the items be returned to the vendor for rework, must be evaluated on a basis of the

urgency of need for the items. The relative economy of rework at company or vendor and even the advisability of rework at all, instead of outright rejection to the vendor, must also be considered. The final decision is beyond the province of Inspection and is normally determined by the purchasing department.

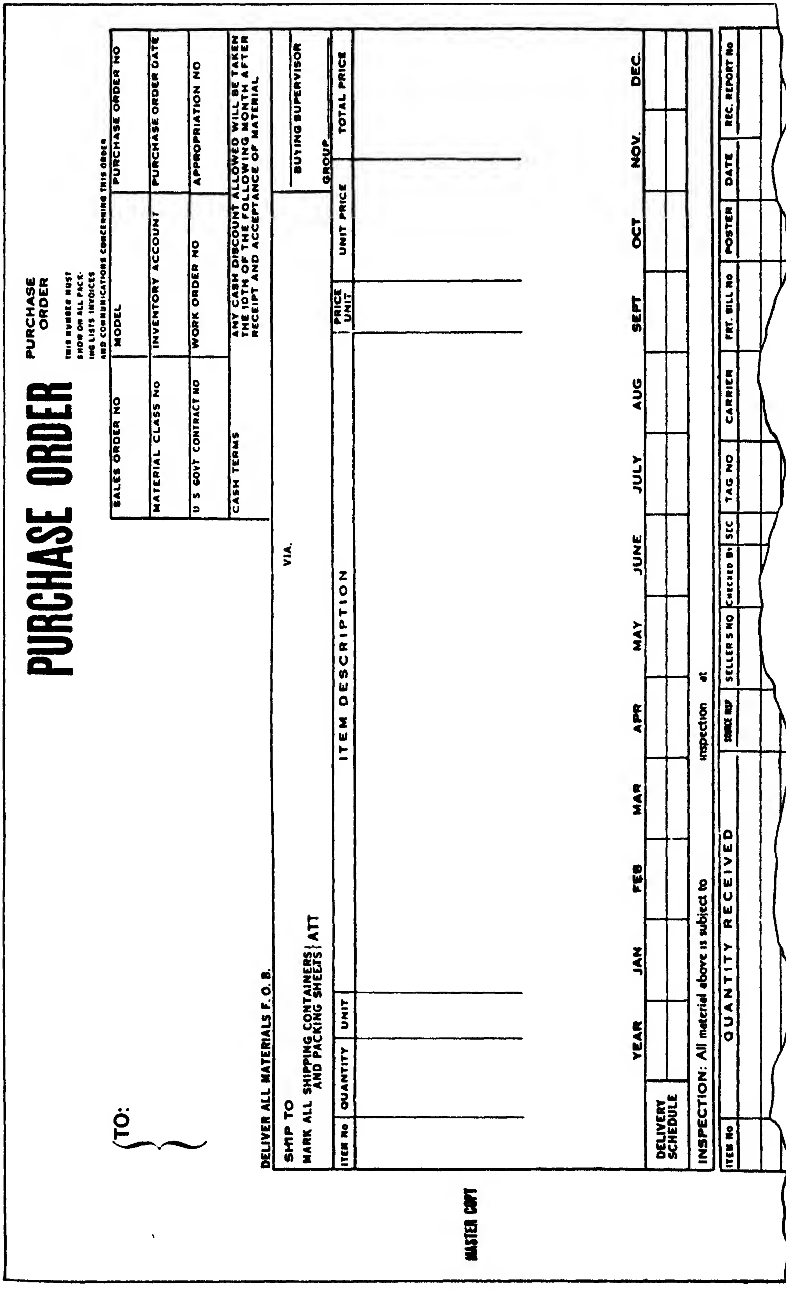
Items which do not meet specifications and which appear unfeasible of rework are also rejected and are withheld by Inspection in the salvage-withholding area, and Purchasing is notified. Final disposition of these items is accomplished at the next scheduled meeting of the salvage board. Detail information regarding receiving rejection and salvage procedures will be found in Chap. 13.

BASIC INSPECTION PROCEDURE

As the basis of all receiving inspection is the *purchase order* issued to authorize procurement of the shipment that is being inspected, this logically becomes the primary document for guiding the receiving inspector. When this document is properly prepared and routed, it is possible to eliminate all other "paper," such as receiving slips and separate receiving reports.

A truly efficient receiving system involves use of a purchase order reproduced from a hectograph master, originated in the purchasing department. Upon initiation of the purchase order, this master (see Fig. 11:1) is filled in with the required data, and copies are duplicated to care for the needs of the purchasing function. Following this action, the master is forwarded to the receiving department for filing.

Upon arrival of the shipment authorized by the purchase order, the proper master (together with masters of such purchase-order change notices as may exist) is removed from files, and appropriate information is entered regarding date received, waybill number, packing-sheet number, and receiving report number. Following this, four copies are duplicated on a similar form, identified as a *receiving report* (see Fig. 11:2). One is for Receiving follow-up files. The remaining three copies, together with the packing sheet and any test reports accompanying the shipment, are forwarded with the shipment to the receiving inspection incoming area.


PURCHASE ORDER

PURCHASE ORDER
THIS NUMBER MUST SHOW ON ALL PACKING LISTS INVOICES AND COMMUNICATIONS CONCERNING THIS ORDER

SALES ORDER NO	MODEL	PURCHASE ORDER NO
MATERIAL CLASS NO	INVENTORY ACCOUNT	PURCHASE ORDER DATE
U S GOVT CONTRACT NO	WORK ORDER NO	APPROPRIATION NO
CASH TERMS	ANY CASH DISCOUNT ALLOWED WILL BE TAKEN THE 10TH OF THE FOLLOWING MONTH AFTER RECEIPT AND ACCEPTANCE OF MATERIAL	

TO:

DELIVER ALL MATERIALS F. O. B.

SHIP TO VIA.

BUYING SUPERVISOR

MARK ALL SHIPPING CONTAINERS AND PACKING SHEETS ATT

GROUP

ITEM No	QUANTITY	UNIT	ITEM DESCRIPTION	PRICE UNIT	UNIT PRICE	TOTAL PRICE

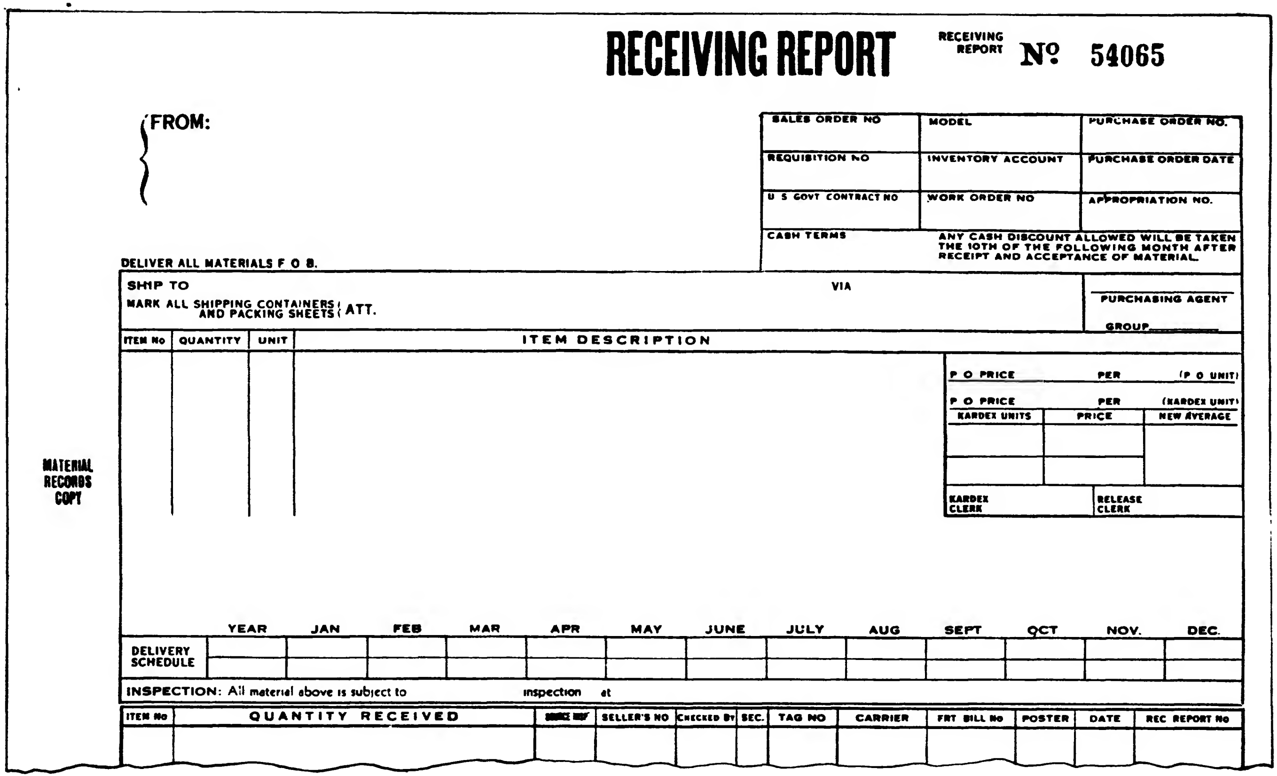
DELIVERY SCHEDULE	YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV.	DEC.

INSPECTION: All material above is subject to inspection at

ITEM No	QUANTITY RECEIVED	SOURCE INSP	SELLER S NO	CHECKED BY	SEC	TAG NO	CARRIER	FRT. BILL NO	POSTER	DATE	REC. REPORT No

MASTER COPY

FIG. 11:1. Typical purchase order form, arranged to serve as a receiving report during inspection of the delivered order.


RECEIVING REPORT

RECEIVING REPORT Nº 54065

FROM:

SALES ORDER NO	MODEL	PURCHASE ORDER NO.
REQUISITION NO	INVENTORY ACCOUNT	PURCHASE ORDER DATE
U S GOVT CONTRACT NO	WORK ORDER NO	APPROPRIATION NO.
CASH TERMS	ANY CASH DISCOUNT ALLOWED WILL BE TAKEN THE 10TH OF THE FOLLOWING MONTH AFTER RECEIPT AND ACCEPTANCE OF MATERIAL	

DELIVER ALL MATERIALS F O B.

SHIP TO

VIA

MARK ALL SHIPPING CONTAINERS AND PACKING SHEETS ATT.

PURCHASING AGENT

GROUP

ITEM No	QUANTITY	UNIT	ITEM DESCRIPTION

P O PRICE PER (P O UNIT)

P O PRICE PER (KARDEX UNIT)

KARDEX UNITS	PRICE	NEW AVERAGE

KARDEX CLERK

RELEASE CLERK

	YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV.	DEC.
DELIVERY SCHEDULE													

INSPECTION: All material above is subject to inspection at

ITEM No	QUANTITY RECEIVED	SOURCE INSP	SELLER'S NO	CHECKED BY	SEC.	TAG NO	CARRIER	FRT BILL No	POSTER	DATE	REC REPORT No

MATERIAL RECORDS COPY

FIG. 11:2. Receiving report, produced from purchase order hectograph master, after addition of receiving inspection data.

Receiving inspection files one receiving report copy, noted with date assigned and inspector's name, as a record of work in process. The two remaining copies accompany the shipment at all times. Upon the required inspection being completed, the inspector enters information on these copies regarding quantities received, accepted, and rejected (attested by his stamp); and both are attached to the shipment upon its being placed in the receiving inspection outgoing area.

One of the completed copies is used by Receiving as authority to issue the formal receiving report, while the other remains with the shipment as authority for its acceptance by the stores group.

The receiving department enters the Inspection receiving report findings in the space provided near the lower margin of the purchase-order *master* (identical with the area used to record inspection data) and reproduces sufficient copies of the formal receiving report. Copies of this formal report replace Inspection's handwritten copy in the storeroom files, notify Purchasing of receipt of the shipment, authorize Accounting to pay the shipper, and replace Inspection's file copy as a record of completed work.

ROUTING AND HANDLING OF WORK

For the receiving inspection activity to function properly, there must be a definite area set aside for this purpose, accessible only to Inspection personnel. Whether or not this must be an enclosed area depends entirely upon the discipline prevailing in the factory. When personnel are not trained to obey company rules implicitly, it may be necessary to enclose all inspection areas. On the other hand, many companies wherein good discipline is maintained simply identify their inspection areas by signs and have boundary lines painted upon the floor.

The inspection area should include definite spaces for accumulation of shipments that are awaiting inspection, those that are completed and awaiting removal by the receiving department, and those that are withheld because of rejection. The only work occupying the inspection benches should be shipments that are being inspected, the next lot to be examined, and the shipment just completed by the inspector. The responsibility of moving

shipments to and away from the inspection benches should be definitely assigned to some member of the inspection crew.

Unless a policy of having only current work in the actual inspection area is followed, the inspection area will soon become so cluttered with shipments that effective work becomes impossible, in a condition similar to that seen in Fig. 11:3.

Shipments placed in the receiving inspection incoming area

FIG. 11:3. Disorderly inspection area, resulting from failure to provide work accumulation areas.

should not be moved out of this area (or from any other portion of receiving inspection) until they are cleared by Inspection.

Handling of work within the receiving inspection area involves delivering incoming shipments to inspection benches as rapidly as is required to keep a steady flow of work moving through the area. Each shipment given to an inspector is accompanied by two copies of the receiving report and all other data forwarded by Receiving. The remaining copy of the receiving report is placed in receiving inspection files as a record of the shipment being in work.

Inspection Dispositions

If the shipment is accepted in its entirety, it is removed from the inspector's bench and placed in the inspection outgoing area,

together with the packing sheet and two completed copies of the receiving report. The Inspection file copy of the receiving report is noted with information identical to that placed upon the other copies, and it remains in Inspection files as a record of completed work, together with all test reports or affidavits received with the shipment.

Should part of the shipment be found defective, the acceptable items are forwarded to the inspection outgoing area in the normal

FIG. 11:4. Inspection area providing established incoming and outgoing accumulation areas and maintaining "good housekeeping." (*Courtesy of Consolidated Vultee Aircraft Corp.*)

manner, with both completed copies of the receiving report; but the rejected parts, accompanied by a rejection notice, are placed in the receiving inspection salvage area to await disposition by the salvage committee. When the whole shipment is found defective, the entire quantity is withheld in the salvage area, together with the two completed copies of the receiving report. In this case the rejection notice informs Receiving of the disposition of the shipment.

Mention has been made of moving the work to and away from the inspection benches. This should be done whenever the size of the shipment permits. Otherwise, it may be necessary to examine shipments in the incoming accumulation area or simply to move the shipment to a position adjacent to the inspector's bench.

Inspector's Action

Each purchase order normally specifies that the shipment shall be in accordance with certain drawings, specifications, catalogues, or the like. In the case of a large receiving inspection group, these reference documents may be delivered to the inspector, along with the shipment, as a responsibility of an Inspection dispatcher. In small inspection groups, obtaining necessary data becomes a responsibility of individual inspectors, who draw upon inspection files as a source.

The examination accomplished by the receiving inspector is normally an operation of inspecting the shipment in accordance with one or more of the following standards: (1) purchase order and all change orders relating thereto; (2) prints of drawings describing the item; (3) catalogues; (4) specifications referenced on purchase order or drawing prints; (5) advance engineering information; (6) inspection checking fixtures, templates, or gages; (7) inspection job instructions; and (8) inspection standard procedures.

Each shipment forwarded to receiving inspection for examination should be accompanied by all physical-test and chemical-analysis reports, magnetic-inspection certificates, X-ray certificate and films, or other special data required by the purchase order. These data should be verified as conforming to requirements, and should be filed by Inspection after all examinations are complete.

The inspector should not, under any circumstances, examine shipments that are not accompanied by a receiving report. Also, receiving reports should not be processed and approved unless they are actually accompanied by the shipment.

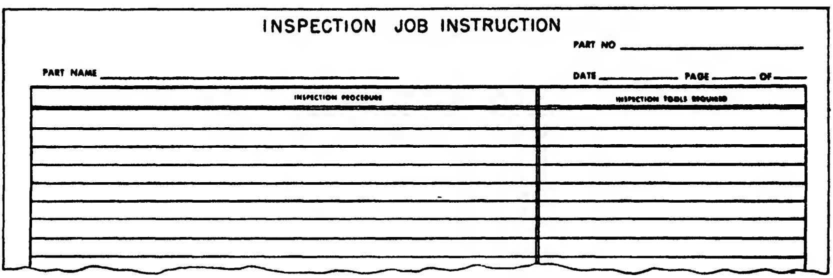
In general, the receiving inspection procedure begins with checking the purchase-order information contained on the receiving report, to verify that the items comprising the shipment correspond with the order. Following this, receiving report data and packing-sheet information should be compared. Drawings, catalogues, specifications, test reports, and the like, listed on the purchase order as governing the acceptability of the shipment, should be obtained by the inspector before beginning detail examination.

Test Reports

When test reports are required and are attached to the receiving report, these should be checked for completeness and for the signature of an authorized member of the vendor company. If these documents are not attached to the receiving report and cannot be supplied by the receiving department, the shipment should be rejected and placed in the receiving inspection salvage area to await disposition by the salvage board.

INSPECTION JOB INSTRUCTIONS

When the identical item is frequently examined by Receiving Inspection on successive shipments, it is desirable to reduce the corresponding inspection procedure to a definite system. This will not only insure the inspection examination's being accomplished


INSPECTION JOB INSTRUCTION

PART NO _____

PART NAME _____ DATE _____ PAGE _____ OF _____

INSPECTION PROCEDURE	INSPECTION TOOLS REQUIRED

Fig. 11:5. Inspection job instruction, used to detail correct procedure for repetitive inspection on examinations.

in minimum time but will also tend to guarantee maximum accuracy and will greatly simplify the process of guiding new Receiving Inspection personnel in rapid, accurate accomplishment of their duties.

This can be accomplished through preparation of inspection job instructions, using a form similar to that shown in Fig. 11:5, which provides for

Part No. Drawing or catalogue number of item to be inspected
Part Name. Description of item, conforming to nomenclature normally appearing on purchase orders
Date. Date of preparation of inspection job instruction

Page _____ *of* _____. Used when instructions require more than one page

Inspection Procedure. Detailed procedure to be followed when examining the item in receiving inspection, itemized and arranged in a sequence that will permit accomplishing the work in minimum time. Also lists points of chronic defects found in previous inspections

Inspection Tools Required. Listing of standard and special tools, gages, templates, or check fixtures required—itemized for each inspection operation.

While inspection job instructions can be prepared for all Inspection groups, they probably are of greatest value in Receiving Inspection. A copy of the proper instruction is given to the inspector by his leadman or foreman at the time the shipment is presented for inspection.

INSPECTION FLOW RECORD

An inspection flow record (see Chap. 2) should be prepared by each receiving inspector, listing all items inspected during his shift and stating the disposition made of each shipment. Copies of this can be filed in the inspection office and used for preparing summaries of receiving-inspection actions for quality-control statistics.

DISPOSITION OF INSPECTED SHIPMENTS

The last receiving inspector to accept a shipment should make certain that all special inspections and tests required (such as magnetic inspection, hardness testing, or performance testing) have been accomplished and properly certified as acceptable by the preceding inspector or inspectors accomplishing these examinations. Following this verification of earlier inspection, the last inspector to accept the shipment should affix his inspection stamp on all accepted items. When the items are too small (or too numerous) to make individual stamping practical, a tag should be attached to one item of the lot, noting the quantity involved and bearing the inspection-acceptance stamp.

Following this, both copies of the receiving report should be stamped and signed by the inspector. At this time the presence

of all required entries regarding quantity and the like is verified. Both copies of the completed receiving report should be attached to the shipment, which in turn is placed in the inspection outgoing area. Identical data should be entered on the receiving report copy held in Inspection files.

Receiving Rejection Procedure

When the inspector cannot accept all or part of the shipment, it is necessary to initiate a rejection notice and to mark all rejected items with a salvage withholding stamp, followed by distribution of copies of the rejection notice and the forwarding of the rejected items to the receiving inspection salvage withholding area.

It is rarely that a receiving inspector will issue a rework notice. Rework of purchased items almost always requires establishment of liability and cost responsibility prior to proceeding with the rework, and these determinations are beyond the duties of Inspection, being, instead, a normal responsibility of the purchasing department.

In all cases of rejection, both receiving report copies should be noted "rejection," followed by indication of the quantity rejected and the rejection-notice serial number. The accepted quantity should also be noted and the inspector's stamp be affixed.

If the entire shipment is rejected, *both* copies of the receiving report should be attached to the rejection notice and should accompany the shipment to the salvage area. When only part of the shipment is rejected, both copies of the receiving report should accompany the *accepted* items to the receiving inspection outgoing area.

Shipments that obviously have been damaged in transit should be inspected at the receiving dock in cases where damage is observed prior to unloading. In these instances it is desirable to notify the company's traffic group (or the person responsible for traffic function, regardless of his actual job title) before removing the shipment from the carrier's vehicle; and the rejection notice should bear the signature of the traffic department's representative.

DETAIL INSPECTION PROCEDURES

Detail inspection procedures will vary with the nature of the shipment, and with the level of quality maintained by the company. Standards, in the form of inspection job instructions and procedures, should be developed to suit individual needs. There are, however, some detail operations that will apply in practically all cases, and these are reviewed in the paragraphs that follow.

Items Requiring Special Tests

In some cases it may be necessary for the receiving inspector to route the shipment to another department or to another group in

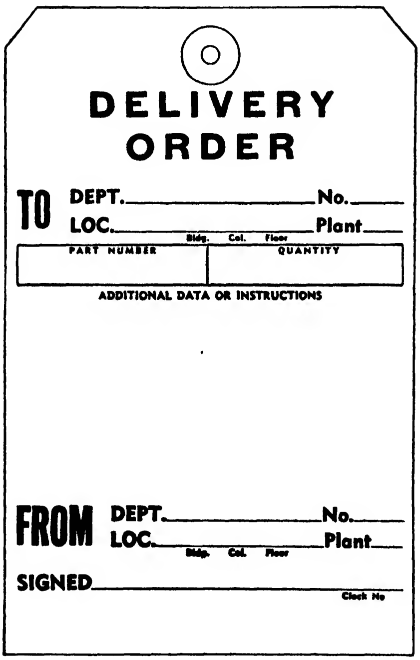


Fig. 11:6. Routing tag used to forward shipments from receiving inspection to other areas for special examination or test.

Receiving Inspection, for accomplishment of additional examination or performance testing on certain specialty items. When the shipment involves specialty items (such as hydraulic, electrical, radio, or instrument components), the receiving inspector should

make a general surface examination and then forward the shipment to the proper destination for required special tests, using a routing tag similar to that shown in Fig. 11:6, marked "preliminary acceptance" and listing the necessary tests.

Both work copies of the receiving report should accompany the shipment. The receiving inspector should note on the Inspection file copy of the receiving report that the shipment has been forwarded for special test.

In the case of shipments requiring special tests, the original receiving inspector, ordinarily, issues a rejection notice only in the event of the items' being received in an incomplete or damaged condition. If all or part of the shipment proves unacceptable when tested, a rejection notice should be issued by the inspector who performs the specialty tests, and this notice should be returned to the receiving inspector with the shipment, after completion of testing. The accepted (and rejected, if applicable) quantity is noted on the back of the routing tag and is stamped by the specialty inspector.

Purchase-order Requirements

It is the receiving inspector's responsibility to ascertain that each shipment meets all requirements of relevant purchase orders. These requirements will vary with different shipments, but in all cases there are certain basic items to be verified.

When the receiving report is reproduced from the identical hectograph master used to issue the purchase order, the required checking can be accomplished with ease, and there is no need for a copy of the actual order. When these documents are prepared separately, it is customary first to verify that the data contained on receiving report and purchase order are identical, before examining the shipment for conformance with the stipulated requirements.

Receiving Inspection Examination

While the detail receiving inspection examination will vary to some degree for different shipments, there are certain basic steps that should be carried out in all cases. These serve as the frame-

work for constructing the detail inspection procedure for a given item, and require the addition of necessary specialized examinations only to establish the complete inspection job instruction for a particular item.

All shipments should be inspected for conformance with applicable drawings, catalogues, and/or specifications. It is important to be certain that the proper revision or change-letter versions of drawings or specifications are used for inspection purposes. Often the requirements of a drawing or a specification may be radically altered by a certain revision. Unless the proper version is used for checking the shipment, there exists the possibility of erroneously rejecting acceptable items or of approving the receipt of incorrect items.

Receiving Inspection normally makes a 100 per cent inspection of all items received from outside production sources. When these shipments are being examined, it is customary, as a minimum procedure, to verify the following: (1) correct part-number identification, (2) proper material, (3) required hardness and/or tensile strength, (4) required surface finishes, (5) workmanship meeting established standards, and (6) all dimensions within drawing limits.

In some companies it is customary to mark certain raw-stock material, such as rod, bar, and tube, with color coding, to identify chemical composition and physical condition. It is highly desirable that these markings be applied prior to the material's being placed in raw-stock stores, and its application be witnessed by a receiving inspector. Unless this is done, positive control of material identity cannot be maintained.

TEST SPECIMENS

When products are manufactured wherein service failure of an item may result in serious loss, it is customary to have chemical and physical tests made of each shipment of certain materials, prior to their acceptance by Receiving Inspection. In the case of critical castings it is usually required that test bars be furnished with each shipment. These are produced at the foundry by pouring a stipulated number of test bars from each heat involved in making the castings. It may also be required that the foundry

furnish X-ray films showing the internal structure of a certain percentage of each shipment of castings.

In all cases it is Receiving Inspection's responsibility to ascertain that the required test bars and/or X-ray films are supplied and that examination and testing of these articles follow. When facilities for chemical and physical testing are not available at the company, it is Inspection's duty to withhold the shipment until all required tests have been accomplished by a responsible laboratory. Only when certified test reports have been received and have been verified by Inspection as meeting all requirements, should the material be accepted and released for forwarding to stores.

When metal shapes, such as rod, bar, and tube, require physical and chemical tests, it is Receiving Inspection's duty to cut a representative sample (sometimes called a "coupon"), of proper dimensions, from an item in each shipment and to forward this to the proper agency for required tests. The shipment should not be accepted until test results show that all requirements have been met.

Whenever testing is required, the inspector should note the test results on both copies of the receiving report or the rejection notice. One copy of the test report should be retained for inspection files and another copy should be attached to the completed receiving report or rejection notice.

MAGNETIC-PARTICLE INSPECTION

All items requiring magnetic-particle inspection should be routed to the proper areas for accomplishment of this work prior to their release by Receiving Inspection. All items found magnetically acceptable should be marked with the magnetic-acceptance stamp (see Chap. 2). This marking should be applied where it will not be obliterated during fabrication operations.

When magnetic-particle inspection reveals the presence of a crack, the defective item should be marked with the salvage withholding stamp. The item should be rejected in the usual manner and placed in the receiving inspection salvage withholding area.

Magnetic-particle indications may be differently interpreted by various inspectors. The final decision on all items rejected

during magnetic-particle inspection should be made by the salvage board. Indications considered by a magnetic inspector to render the item unacceptable may prove to be inconsequential, upon grinding out the apparent defect to determine its actual magnitude, or upon proof-loading the rejected item.

All items rejected by magnetic inspection and subsequently accepted should bear the magnetic acceptance stamp. This should be applied so as slightly to overlap the salvage acceptance marking.

When production items receive magnetic-particle inspection, the shop order accompanying the items should also receive the magnetic acceptance stamp opposite the entry specifying magnetic-particle inspection, if all the items are accepted. When all or part of the items are rejected, a notation of "See rejection notice no. ———" should be placed in the same location on the shop order, with indication of the quantities accepted and rejected and the inspector's stamp affixed to the note.

X-RAY INSPECTION

Whenever X-ray inspections are required, a test report should be prepared, listing exact conditions and results for each test. Each report should list voltage, current, exposure time, distance between item and film, filters, development time, film type, and all other information necessary to permit duplication of the test. All X-ray negatives should be identified with the corresponding test report number and should be filed with a copy of the report.

After preparation of the required X-ray negatives for a given lot of items, the X-ray inspector should examine the negatives and decide the acceptability of the items. Accepted items should receive the X-ray acceptance stamp. Rejected items should be processed in the usual manner.

When rejected items represent a considerable unit cost, it is desirable to select from the rejected lot one item showing the greatest number of defects and to subject this to proof-load tests, to determine the effective magnitude of the apparent defects. In some cases the results of such a test may make it possible for the salvage board to accept items that otherwise would be scrapped.

When items are given X-ray inspection on a sampling basis

(*i.e.*, actual X-ray inspection of a small percentage of the total lot), it is necessary to establish percentage limits for defective items that can be tolerated without necessity of 100 per cent X-ray inspection of the lot. With highly critical items, it is normal practice to conduct a 100 per cent examination if a single item in the sample is rejected, while in the case of less critical items it may be possible to tolerate rejections equal to a small proportion (perhaps 2 per cent) of the total-lot quantity.

RECEIVING INSPECTION STATISTICS

Until the integrity of a vendor is proved, it is usually good policy to maintain rigid inspection over all shipments received. As it becomes evident that the vendor's products are consistently within allowable limits, indicating sound control of product quality, it is practicable to relax receiving inspection procedures and to operate on a sampling basis, with allowable limits for defects within the samples that can be tolerated without necessity of 100 per cent examination of the shipment. Memory and opinion should not be depended upon in establishment of the reliability of various vendors. Instead, accurate records should be maintained of the rejections in each shipment from every vendor.

The data compiled in such records are often extremely enlightening. In an analysis made by the Bell Aircraft Corporation [1] of shipments received from 458 vendors, it was found that

277 vendors supplied items of which 0.0 to 1.99 per cent were defective.

39 vendors supplied items of which 2.0 to 4.99 per cent were defective.

31 vendors supplied items of which 5.0 to 9.99 per cent were defective.

44 vendors supplied items of which 10.0 to 19.99 per cent were defective.

36 vendors supplied items of which 20.0 to 49.99 per cent were defective.

31 vendors produced items of which 50.0 to 100.0 per cent were defective.

[1] Based upon data contained in "Bell Puts Teeth into Quality Control," by Herbert Chase, in *Wings*, September, 1944, p. 1183.

From these data it was immediately apparent that a large majority of receiving rejections originated from improper quality control by a small percentage of the vendors and that a large portion of the total receiving inspection effort was being spent to guard the company from the negligence of a small group. On this basis, a list of approved vendors was prepared, eliminating those chronic offenders who failed to improve upon adequate notification, and the cost of receiving inspection was reduced accordingly.

BASIC PROCEDURE FOR OUTSIDE PRODUCTION INSPECTION

Whenever extensive outside production work is purchased, it becomes necessary to establish a definite inspection procedure that will insure maintenance of required quality on work accomplished by the outside sources, without the necessity of 100 per cent inspection of every item supplied by these sources. This can be done through control of inspection by the outside producer.

When inspection at source is desired for outside production work, the most satisfactory operation plan appears to be one involving the following:

1. The outside production source is investigated by company Inspection, to determine suitability of production equipment and methods, competency of inspection personnel, and adequacy of inspection plan.
2. Upon company Inspection's being satisfied that the outside production manufacturing and quality-control methods are acceptable, the outside producer is certified by company Inspection as competent, and certain designated individuals in the outside producer's inspection department are authorized to accept items for the company and provided with company inspection stamps.
3. A sampling inspection is made of all parts received from the outside producer, usually on a basis of 2 per cent of each shipment.
4. The percentage of defects to be allowed in these samples is established. This may range from 0 to 4 per cent.
5. Immediately upon any shipment's exceeding the allowable defects, the outside production source is notified that the erring inspector (identified by his stamp number) must be withdrawn from work on company parts, his stamps immediately returned to the company, and another inspector selected by the company Inspection representative.

In this arrangement, the company inspector assigned either as resident or as visiting representative to the outside production source functions largely in a liaison capacity. Occasional spot checks of the product are made at the outside production plant, and the current manufacturing and inspection methods of the plant are periodically reviewed.

CHAPTER 12

FABRICATION AND ASSEMBLY

Manufacturing of detail items required for constructing assemblies is usually termed *fabrication*. Operations normally associated with fabrication are sheet-metal work, machining, welding, and such *processes* as heat-treating, wood-turning, and painting.

Fabrication inspection is one of the most important quality-control steps involved in the entire manufacturing sequence. The completed end item cannot be better than the detail items used for its construction. Further, the expense of replacing defective items during fabrication will be small in comparison with the cost of replacement upon discovery during final assembly or after delivery to the customer.

An assembly is created whenever two or more detail items are joined. The only normal exceptions to this rule are welded and brazed assemblies, which are usually considered in the same light as detail items, owing to the impracticability of readily removing and replacing a single detail of the assembly.

Various forms of assemblies are encountered. A small, relatively simple end item may comprise but a few assemblies. More complex products may involve sub-subassemblies joined to form subassemblies, which in turn are joined to form major assemblies of the completed end item. In any case the basic responsibilities of assembly inspection will be identical, and the degree of inspection work accomplished will be governed by the quality level to be maintained.

An integral and extremely important part of assembly inspection is final-assembly testing. At this point previous inspection action has verified that all details were fabricated in accordance with established standards; and properly assembled through various stages of subassembly and final-assembly work to produce

an end item containing all items required to produce a satisfactory product.

However, the preceding inspection does not positively guarantee that the completed end item will function satisfactorily. Inaccurate adjustments, tolerance accumulations, and the possibility of hidden defects not revealed by preceding inspection may prevent proper functioning. In practically every case, operational testing must be accomplished at the conclusion of final-assembly work, before Inspection can certify that the end item is ready for delivery to the customer.

DETERMINING CAUSES OF DEFECTS

Inspection's handling of fabrication and assembly work should not be confined to simple rejection of defective items. This would be purely negative action and would not assist in eliminating causes of defects. An important phase of all inspection is ascertaining causes of repetitive defects and determining methods for their elimination.

Investigation of chronic defects revealed by inspection is a function of the quality-control engineer, who reports the findings on each case to the chief inspector. The essential facts of each case are conveyed to the executive responsible for manufacturing. However, the total responsibility for this function should not be placed upon the quality-control engineer. Each inspector should be alert for evidence of chronic defects, attempt to analyze their cause, and arrive at remedies for each. These remedies should be called to the attention of manufacturing supervision in an attempt to eliminate the causes at the working level, instead of going up to top management through the inspection office and then down through the manufacturing departments to the working level. Defects due to engineering errors should be reported to the Inspection quality-control function.

Application at the working level of remedies for manufacturing defects originated by Inspection requires the best of cooperation with Manufacturing supervision. This friendly cooperation should always exist. When it does not, the usual cause is an arbitrary, unyielding attitude on the part of Inspection or of individual inspectors. Inspection (and each inspector) should

never lose sight of the basic fact that theirs is a *service* function. This involves assisting Manufacturing in producing items that meet quality standards established by company top management and should never be distorted to become simply a policy of rejecting defective parts. Everyone loses when items must be reworked or scrapped, including Inspection, as the company's ability to continue successfully in business is governed by the degree to which items of the required quality can be produced at minimum cost.

TYPES OF FABRICATION INSPECTION

There are two basic methods applicable to the examination of items during fabrication operations. These are *flow inspection* and *central inspection.* Both methods are applicable also to assembly inspection, but probably flow inspection finds its greatest application during fabrication operations.

Flow inspection, sometimes called "floor inspection" or "line inspection," involves examination of fabricated items within the production areas, prior to their being forwarded to the next operation. The designation of this form of inspection is derived from the quality examination, being a part of production "flow"—with items going directly to an inspection station in the production line after completion of an operation or a small group of related operations.

Central inspection, sometimes referred to as "booth inspection," involves an inspection booth or area serving a manufacturing department or a group of related departments. In some cases inspection is not accomplished until items are completely fabricated, while in others the items may be examined after each operation or group of operations. In either case it is necessary to move the items to the inspection booth, to store them while awaiting inspection, and then to return them to the fabrication area for the next operation.

Flow Inspection

Incorporation of inspection directly into the production flow has the proved advantages of increasing productive output and

of reducing manufacturing labor costs. In addition, rework and scrap expenses are certain to be markedly reduced, as errors are detected almost immediately. This means that fewer items will require rework. Spoiled items can be scrapped at the point in production where the defect occurs, rather than pass through additional expensive operations before being detected upon forwarding to a central inspection booth.

Obviously, flow inspection finds its principal application in shops in which a true production "flow" exists. Even in a job shop, however, a modified form of flow inspection often is valuable. One or more "floor" or "patrol" inspectors can be assigned to rove through designated factory areas, checking the first piece produced on each operation and shift, then returning at intervals to check additional items. These inspectors soon become familiar with chronic trouble spots, and may find it desirable to check every twentieth piece of a certain item produced on a turret lathe, while checking only every hundredth piece of another item produced on a screw machine. In each case sufficient items are checked to guard against generation of excessive rework and scrap. When statistical quality-control methods are applied, the required percentage of items to be inspected to maintain a specified quality level can be accurately forecast.

A rearrangement of a shop manufacturing large quantities of Diesel-engine fuel pumps, to permit installation of complete flow inspection, reduced rework and scrap from 2.7 to 0.3 per cent in a short time. This installation was arranged in the following manner.[1]

Key to the solution is a physical arrangement which permits inspection (if required) of each part after each machining operation without loss of time and without accumulation of excessive inventory. The layout of the new shop was designed with this objective in view.

The layout adopted for the line producing large parts is based on the zigzag flow principle. Parts leaving the machine on which the first operation is carried out, are placed by the operator on the adjacent inspection bench. They are inspected on the spot and placed back on the bench ready to be picked up by the operator of the machine per-

[1] "Flow Inspection Cuts Rejects 90 Per Cent," *Factory Management and Maintenance*, July, 1948, pp. 72–74.

forming the second operation. The process is repeated right down the line.

Racks underneath the inspection bench allow a small reserve of parts to be stored. This supply is just enough to keep the line in balance when temporary delays are experienced because of machine breakdown, operator absence, or the like.

Actual flow is planned on a 5-min. cycle. Whenever possible, operations taking less than 5 min. are grouped to form composite operations.

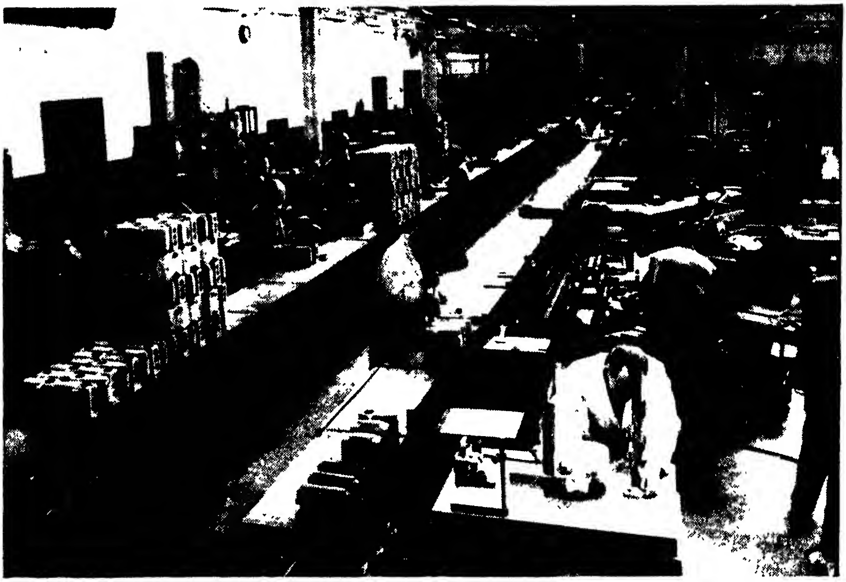


FIG. 12:1. Inspection lines parallel production flow in this Diesel-engine fuel-pump factory. (*Courtesy of The Machinist.*)

That is, the same operator takes the parts from machine to machine to complete the group of operations before passing the parts back to the inspection bench. When the most remote machine in a group is not within easy reach of the inspection bench, a gravity roller conveyor is installed to transport the parts.

At those operations where it is necessary to clean a part before inspection, the operator places it in one side of a pressure-jet washing machine adjacent to the inspection bench, and it is removed by the inspector from the other side.

The machines for small-parts production are grouped in seven sections, each section comprising a row of machines along each side of a

conveyor belt. Each machine is fitted with a chute, on which the operator places the part when the operation is completed. The part slides down the chute and onto the conveyor belt, and is carried directly to . . . inspection . . . at the end of the section.

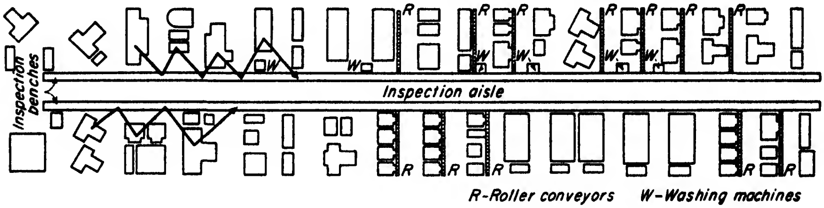


FIG. 12:2. Flow diagram of inspection arrangement shown in Fig. 12:1.

CENTRAL INSPECTION

Examination of all items in a central area or booth, normally enclosed and with windows for receipt and delivery of parts, represents a traditional inspection arrangement that is disappearing from the scene in many modern production plants; although many plants operate on a combination of flow and central inspection. Production must bring items to this area, request their examination, and await their return at Inspection's pleasure. When this scheme is exclusively used in a production operation, Inspection is not functioning in its true role of a *service* to production, but instead is the master of production. Obviously this condition is functionally incorrect and must be rectified if maximum production efficiency and minimum costs are to be realized.

The principal disadvantages of central inspection for a production operation are (1) excessive labor expense in moving parts to and from inspection; (2) long storage time in inspection, contributing to excessive work-in-process inventory; and (3) grave possibility that a large quantity of defective parts may be produced before an error is discovered.

The true magnitude of material-handling expense is often overlooked by manufacturing executives, and this cost is always magnified when central inspection is employed. In some cases it has been found that 70 per cent of the total direct fabrication labor is expended on material handling and only 30 per cent on actual manufacturing operations.

On the other hand, central inspection may be the only logical operating plan when manufacturing is accomplished on a job-shop or semirepetitive basis. Individual manufacturing releases then involve small quantities of parts, and there is no true production flow. The basic objections to central inspection are no longer valid, and this scheme may well represent the most economical plan.

It is probable that central inspection sometimes may provide improved Inspection supervision and better control of inspection realization or efficiency. This factor is quite important, as Inspection is an indirect function, forming part of the "burden," or overhead expense, of operating the factory and producing the product, and it must always be kept as low as is practicable.

INSPECTION REALIZATION

Realization, as related to the economics of manufacturing, is a criterion of efficiency. It is usually expressed as a percentage indicating the relationship between actual performance and a standard representing the maximum efficiency considered practicable of realization. Inspection does not lend itself as readily to the establishment of accurate standards as do direct labor operations involved in manufacturing operation. However, it is practicable to establish inspection standard times for specific items when production quantities are sufficient to justify the expense of time studies.

There are three basic means by which inspection realization can be controlled and measured. The choice of method will be governed by circumstances existing in a particular factory for a given product.

One method involves a standard *rate of inspection* for each item or operation, establishing a standard quantity of items to be inspected per hour. When the standard is accurately established through proper motion-study and time-study work, the relative efficiency of each inspector may be fairly accurately determined.

In some instances a direct wage incentive or bonus has been paid to Inspection personnel, following customary piecework practice. This method is open to criticism, as the thoroughness of

inspection work may deteriorate and the average quality of the end item may suffer accordingly.

When the manufacturing plan involves mass production and thereby lends itself to the establishment of true production flow, it is desirable to make inspection part of this flow. This can be done through proper production planning, adequate plant layout, and accurate production standards that permit balancing Inspection personnel, to obtain maximum realization for the rate of production. When this is done, inspection stations are established in the same manner as production work stations, and the inspectors are balanced out in the same way that the Production personnel are balanced out to eliminate unnecessary personnel at a production station.

Regardless of the method selected to measure inspection realization, it is important that careful attention be directed to accurately recording and analyzing Inspection efficiency reports. Whenever it is seen that a segment of Inspection is failing to maintain normal efficiency, it is vitally important that Inspection management immediately investigate, to determine the cause and to apply necessary remedies.

BASIC PROCEDURE FOR FABRICATION INSPECTION

The basic document for guiding the fabrication inspector is the *shop order,* issued to authorize manufacture and detailing the operations required to produce the item. This order normally lists each point in the manufacturing sequence where inspection shall take place. Spaces are provided on the order for application of the inspector's stamp after each point where inspection is specified. The quantity of items in the production release (or lot) is also specified.

The inspector's responsibility is, first, to verify the count and make certain that all items comprising the particular lot are actually in the group being inspected. The items are then examined to make certain that all operations performed since the last previous inspection point have been correctly accomplished in accordance with applicable drawing prints and specifications.

In some cases an inspection *operation sheet* may be provided, listing the gages and fixtures required for examination of the

item, necessary reference prints and specifications, and detailing a step-by-step procedure for verifying the correctness of the item. When experienced, reliable inspectors are employed, these detailed job instructions are not ordinarily required. On the other hand, if inexperienced inspectors must be employed, this is probably the most feasible method of securing accurate, consistent work.

In all cases it is highly desirable that each inspector maintain an "inspection flow record" of his work and inspection action (see Chap. 2). This is simply a tally of the items handled by each inspector during his shift, showing the quantities accepted, returned for rework, and rejected. Different kinds of items will be recorded separately, of course, so that the consolidated records will provide an accurate count of the production achieved on each shift.

Checking and Reference Data

A copy of the drawing print providing manufacturing information is prerequisite to inspection examination of the item. The print is used to check for correct appearance and to verify dimensions, heat-treatment, and finish requirements, as well as all special requirements not completely detailed on the shop order—such as location and dimensions of punched holes produced by a die.

Certain operations, such as heat-treatment, may be specified as being in conformance with certain specifications. It is important that the inspector have these specifications available for reference. During inspection of the first few items, the inspector may frequently refer to these specifications, but as time passes the need for frequent reference should diminish, as the inspector becomes familiar with specification requirements.

Various standard gages will be required for fabrication inspection. In the case of extensive production, there may be special gages provided to reduce inspection time by gaging dimensions rather than actual measurement. Templates are often provided for checking flat-pattern blanks, prior to bending and forming, with additional special templates used to check contours and angles of the finished item.

When interchangeability is critical, there may be special checking fixtures provided for testing dimensional accuracy, particu-

larly that of surfaces and holes on different planes. Fixtures may be used also when interchangeability is not highly critical, but when the shape of the item makes dimensional verification through actual measurement laborious and costly.

In some cases of high production of extremely precise articles, such as Diesel-engine injection pumps, there are provided go and not-go gages for checking each dimension of every item. The basic responsibility for dimensional accuracy then rests no longer with the fabrication inspector (his job is simply one of correct usage of gages), but is almost entirely that of the gage-control activity.

When large quantities of special gages are used for inspection checking, these are often arranged in groups of related gages to reduce inspection time and to insure use of the proper instrument. Application of this method was accomplished by one precision shop in the following manner: [2]

> At stations where parts with a number of dimensions to be checked are received, or where many different kinds of parts are being machined in the section, gages are mounted on a special frame. Frequent picking up and putting down of gages is eliminated and the inspector's hands are left free to handle the parts.
>
> Gages are mounted on the frame in the sequence of use. Groups of gages to cover up to eight different dimensions can be accommodated on each frame. Three of these frames fit the length of the bench so that the inspector can have immediately available the gages needed to check 24 different parts or dimensions. Inspectors' chairs are fitted with ball-bearing casters and run on rails, enabling them to move their chairs from frame to frame without rising.

INSPECTOR'S ACTION

A prime responsibility of fabrication inspection is checking the *first piece* produced on a machine at the beginning of each lot involving a new or different machine setup or a change in machine operators. After determining that the setup will produce an accurate item, the inspector approves its use and production begins. In some cases the approved first piece is identified with special stamping and is tagged, then retained by the operator as a sample,

[2] *Ibid.*, p. 74.

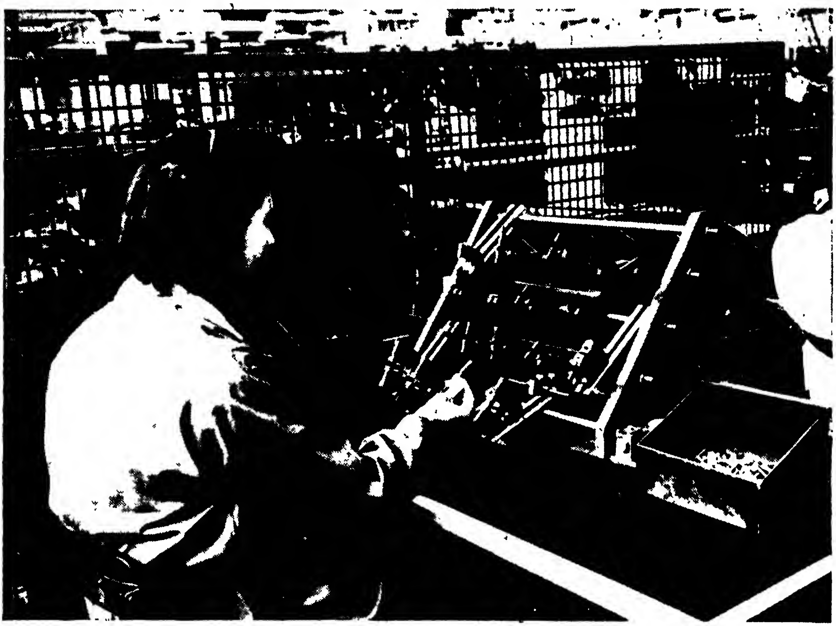


FIG. 12:3. Group of related inspection gages mounted to facilitate rapid, accurate usage. (*Courtesy of The Machinist.*)

to be sent later to Inspection, with the remainder of the items comprising the production lot.

ACCEPTABLE ITEMS

When an inspector determines that items are acceptable, it is normal practice to indicate inspection by marking the shop order with the inspector's "accepted" stamp and by placing identical marking on each accepted item. When items are not suitable for steel stamping, a rubber stamp and marking ink may be used. Items too small for stamping of any kind should be placed in a container bearing a tag that shows the Inspection acceptance stamp.

Items made from heat-treated material should not be accepted until the heat-treatment has been verified by proper tests. In these cases a heat-treatment acceptance stamp should appear on the item, in addition to the fabrication acceptance marking.

After marking all acceptable items, the inspector should place

these, together with the applicable shop order, in the inspection outgoing area, for disposition by the production-control dispatching system. In no case should Inspection accept responsibility for moving the accepted items to their next destination in the manufacturing cycle, except in certain continuous-flow production cycle arrangements.

Reworkable Items

It may be found that all or a portion of a particular lot of items do not meet requirements but deviate in a manner that permits reworking to produce acceptable items. A typical instance would

REWORK NOTICE No. xxxxxxx

Part No. ______ Part Name ______

Qty ______ Rework By Dept ______ Shop Order No. ______

Defect ______

______

Return to: ______

Inspector ______ Shift ______ Date ______

See opposite side for special instructions

Reworked by:

Name ______ Dept. ______ Clk No ______

Date ______

Fig. 12:4. Rework notice, used to return items to shop departments for correction of deficiencies.

be an oversize outside diameter that could obviously be brought within drawing limits by additional turning or grinding.

Reworkable items should be returned to the department that forwarded the items for inspection, accompanied by a suitable rework notice (see Fig. 12:4), clearly stating the nature of the work to be accomplished. The acceptable items in the lot may be retained by Inspection until the reworked items are returned, and the total acceptable items can then be dispatched through Production Control to the next operation; or they may be handled as a "split lot." With a continuous-flow production cycle, the acceptable items, however, are normally forwarded immediately to the next operation, and the accepted reworked items follow at a later time. In this case it is not necessary to retain identity of individual production-lot releases, and the important matter is to

keep as many items as possible flowing through the fabrication cycle.

In some instances it may be discovered that items are deficient in an operation accomplished long before the immediate inspection point, and that rework must be accomplished by a department or a group other than the one presenting the items for inspection. When this condition exists, it is obviously impractical to return the reworkable items to the factory group who last sent them to Inspection; for in all probability the equipment for rework will not be in that group. When this situation is encountered, it is preferable to reject that portion (see Chap. 13), to be forwarded to the salvage-withholding area for salvage action. Unless this is done, considerable complication of production-control dispatching may arise, while the procedure for handling salvage is defined and routing methods are established.

Rejected Items

Items not acceptable as manufactured and not feasible of rework through normal methods must be rejected. A *rejection notice* (see Chap. 13) is prepared, and the unsatisfactory items, together with the notice, are forwarded to the salvage withholding area for salvage action. Rejected items are ordinarily identified with the salvage withholding stamp, to avoid possibility of accidental usage.

At the time a portion of the lot is rejected, the shop order should be marked "Note Rejection," and the quantity of rejected items, date of rejection, and rejection-notice serial number should be entered on the back of the order (or on the face of the form, if space is provided). It is not necessary to obtain a split-lot shop order for the rejected items, as the rejection notice is sufficient to authorize their movement and disposition.

Split Lots

In a majority of rework cases only a small portion of the items comprising the lot are defective. The remainder are acceptable and may require immediate forwarding to the next manufacturing operation to avoid production shortages.

When this is the case, it is customary for Inspection to request that Production Control issue a *split-lot shop order*. This is simply a new shop order, duplicating the information contained on the original order submitted to Inspection with the items, except that the quantity specified is that of the defective items. This new split order accompanies the rework items, is stamped off by Inspection when the rework is satisfactorily accomplished, and items and order are then forwarded in the usual manner. The original order accompanies the acceptable items and is noted with the fact that a split order has been issued.

When all items in the lot are to be reworked, a split order is usually not necessary. In fact, issuance of a split-lot order represents an additional burden on Production Control and should be requested only when delay in forwarding the acceptable items may create a shortage. Otherwise, space permitting, it is probably better to hold the acceptable portion of the lot in Inspection until the rework is accomplished, forwarding the entirety of acceptable items in the lot and rejecting those that did not rework satisfactorily.

TYPICAL FABRICATION INSPECTION

Detail procedures for fabrication inspection will vary with the nature of the product and the quality level maintained. While it is obviously impractical to outline detail inspection methods for even a minority of the possible combinations of product and quality level, it is feasible to outline a few procedures for certain basic fabrication operations, as an indication of the general nature of fabrication inspection.

The basic inspection operations in practically every case will involve one or more of four factors: (1) quantity, (2) dimensions, (3) hardness, and (4) quality. Often items are inspected in a *semifinished* condition, being checked for but a portion of the complete cycle of operations required to produce the item. These semifinished items often do not entirely resemble the "picture" shown by the drawing print, and inspection must generally be confined to determining quantities, quality of workmanship, and presence of conditions that might prevent the items from being acceptable upon completion of subsequent operations.

Sheet-metal Items

The first step in the inspection procedure is counting the items. If the quantity delivered to Inspection varies from that shown on the shop order, this should be noted, to avoid Inspection's being

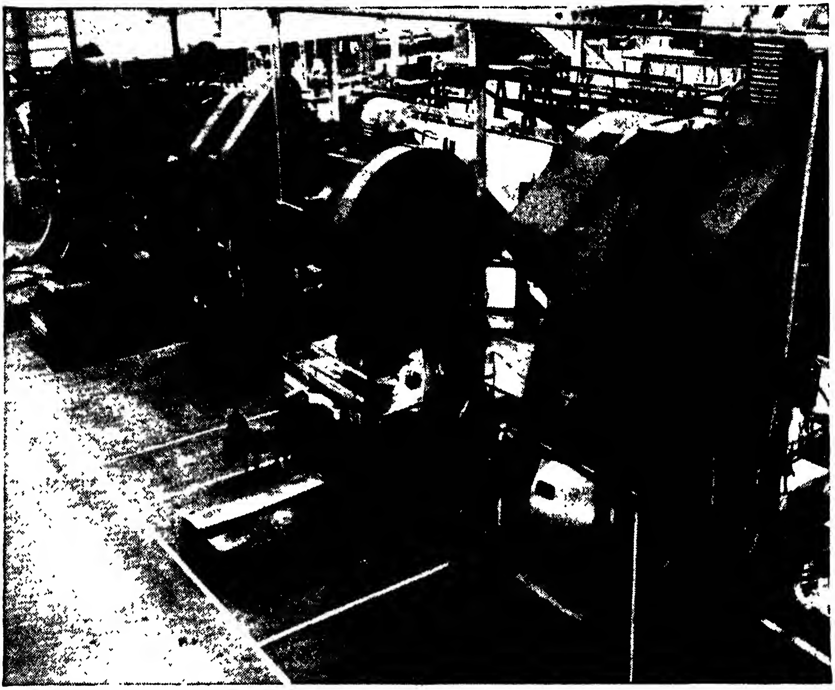


FIG. 12:5. Items produced with mechanical presses, such as these, rarely require individual inspection if accurate dies are used.

held liable for the loss. Gage and kind of material should then be verified as being in accordance with drawing-print requirements. When a definite hardness (or tensile strength) is specified, this must be verified by suitable hardness tests, followed by applying a hardness acceptance stamp to all items found within required limits.

Following verification of quantity, gage, and material, the items should be checked for dimensional accuracy. When the drawing print fails to provide all required information, it is obvious that a template or other tool must have been used during

manufacture (excepting, of course, experimental items laid out by hand), and this should be obtained by the inspector and used to verify dimensions. Whenever this is done, it is important to make certain that the template or other tool bears a tooling-inspection acceptance stamp, and relates to the same change version of the item as that appearing on the drawing print used for reference.

After these conditions have been verified, the inspector should make a general surface examination, to ascertain that the workmanship is satisfactory, and that each item is free from objectionable scratches, burrs, marred areas, or cracks. Upon the item's meeting all requirements, it should be identified with an Inspection acceptance stamp adjacent to the part number stamped on the item (assuming that each item bears a part number) and then placed in the location used to accumulate acceptable items from the lot being inspected.

Machined Items

The general procedure to be followed in inspecting machined items is similar to that employed for sheet-metal items, but a much higher degree of precision is ordinarily required. Dimensions may be highly critical with regard to the item's ability to assemble properly with mating items, and they must be within the limits specified on the drawing print. In many cases these have been carefully calculated with reference to those on mating dimensions, to insure that even if the dimensions on both mating items are at their most unfavorable limits, assembly will still be possible. These limits often represent the absolute maximum allowable; and should they be exceeded, assembly may be prevented.

In other cases, such as limits on corner and fillet radii, the strength or fatigue resistance of the item may be dependent upon maintaining dimensions within limits. In general, machined items are often highly critical in regard to assembly and strength requirements, and demand the highest type of precision inspection work.

A variety of precision gages and measuring instruments are used in the inspection of machined items. To avoid the expense

of duplicating precision measuring equipment, it is customary that all precision inspection of forgings, castings, and machined items delivered to Receiving Inspection from vendors and outside production sources be inspected by the inspection center assigned to machine-shop work and then returned to Receiving Inspection. Samples of all forgings and castings are usually inspected prior to the authorizing of a production run by forge shop or foundry.

Machined items requiring hardness tests, magnetic-particle or fluorescent-penetrant inspection, or other special testing should have this work accomplished before application of the Inspection acceptance stamp.

It is customary for machine-shop inspection to verify the accuracy of all machine setups prior to starting a production run. Following this, the first piece is thoroughly inspected and approved before production continues. During the production run, when floor or patrol inspectors are used, it is customary to spot-check individual operations at specified intervals to make certain that the setup remains correct and that proper tools are being used.

Fusion-welded Items

Inspection should refuse to accept fusion-welded items for examination unless all excess weld bead, flux, and slag have been removed. Common defects visible after arc welding include oxidized streaks along the weld, indicating excessive heat. A long ripple-weld bead indicates excessive heat when gas welding is employed.

Weld beads should be comparatively smooth and of reasonably constant thickness, and should be free from blowholes and porosity. Pitting, burning, cracking, or distortion of the material adjacent to the weld are grounds for rejection, as is evidence of lack of fusion or "hot-putty" weld beads.

All critical welded items should be checked for evidence of cracks in or adjacent to the weld. In some cases magnetic-particle inspection may be used, in addition to visual examination. Cracked welds can usually be repaired by grinding out the defect and rewelding. Arc welding is usually preferable for rewelding,

to avoid excessive heating and possible burning of the metal, even though the original joint was produced by gas welding. When a highly critical item is involved, it may be necessary to use magnetic-particle inspection to make certain that the crack has been entirely ground out before rewelding.

When the welded items are critical, it is good practice to have all scrap examined by the inspection laboratory, with a record of the welder producing each. Adequate cross sections of the weld should be prepared and etched. These will provide an excellent criterion of the skill of each welder, without the expense of special test specimens; and they will serve as an unusually accurate check, as the welder will have only used normal care on production items, while a special effort is likely when it is known that the specimens are for test purposes. The amount of weld penetration, degree of slag inclusion, and porosity are items normally checked during examination of weld specimens. A record should be maintained of all weld-specimen examinations.

ASSEMBLY INSPECTION

Assembly inspection is similar to fabrication inspection, with the addition of requirements for determining that the proper kind and quantity of detail parts have been joined in the correct manner, followed by verifying that all adjustments have been correctly accomplished and that the completed end item will function correctly.

All work accomplished by assembly inspectors can be grouped into four broad classifications: (1) bench assembly, (2) subassembly, (3) final assembly, and (4) operational testing. Bench assembly involves small assemblies capable of being handled to advantage on benches. These are usually joined at a subsequent point in the production line, to become subassemblies, or they may be parts of installations placed in the final assembly.

Subassemblies are larger and more complex groupings of detail parts and small assemblies, often assembled in jigs, to insure dimensional interchangeability, and forming major portions of the final end item. At final assembly, various subassemblies are joined, together with certain installation parts, to form the completed end item.

Inspection of bench assemblies is normally accomplished in the same manner as fabrication inspection. In fact, fabrication and bench-assembly examination often is handled by the same sub-

FIG. 12:6. Electrical bench assembly is typical of the work relating to this class of inspection.

division of the inspection department. Bench assemblies are small and can be handled and routed through the shop in the same manner as that used for detail parts, and the inspection plan of operation is, quite naturally, established to parallel the production flow.

Subassemblies and major assemblies may be quite large, are often complex, and usually have individual identity established by the serial number of the end item of which they will form a

part. In these cases the production-control plan is often different from that followed for fabrication, to avoid the necessity of issuing lengthy assembly orders for each and every assembly; and the inspection procedure is modified accordingly.

Further variations in assembly inspection procedure will exist between the methods best suited to lot production (where the total production is small and is released to the shop in separate lots), and those adaptable to continuous-flow production, wherein a given production line may operate for months on an identical product, and individual lots with corresponding orders are not encountered.

ASSEMBLY INSPECTION FOR LOT PRODUCTION

When a shop is operating on a lot-production basis, the bench-assembly inspection procedure will normally be identical with that used for fabricated parts. Separate shop orders will accompany each lot of parts, and these will be used by Inspection as the basis for quality examinations.

Large subassemblies and major assemblies need not be accompanied by detail assembly orders for each unit. A more practicable system is issuance of an *assembly-station list,* showing the assembly and installation work to be accomplished at each production station on all models or variations of the end item. The various sections of this list are normally identified by "operation numbers." The list is used as a reference document by shop supervision and workmen at each assembly station, and is kept up to date by Production Control to reflect current changes in the product.

When an assembly station list is employed, Inspection does not have individual orders to stamp off to certify acceptance of the items, and another document should be introduced. This can be an *operation inspection list,* similar to that shown in Fig. 2:7, prepared by the inspection office for each end item.

Each assembly accepted by Inspection should be stamped to indicate acceptance, in addition to the stamping of the operation inspection list. Copies of all operation inspection lists pertaining to each end item should be accumulated in the *inspection log* established for that item. This log, which provides a complete

record of the status of each end item as it is delivered to the customer, is often invaluable when unsatisfactory conditions develop after delivery, or when the customer orders spare parts.

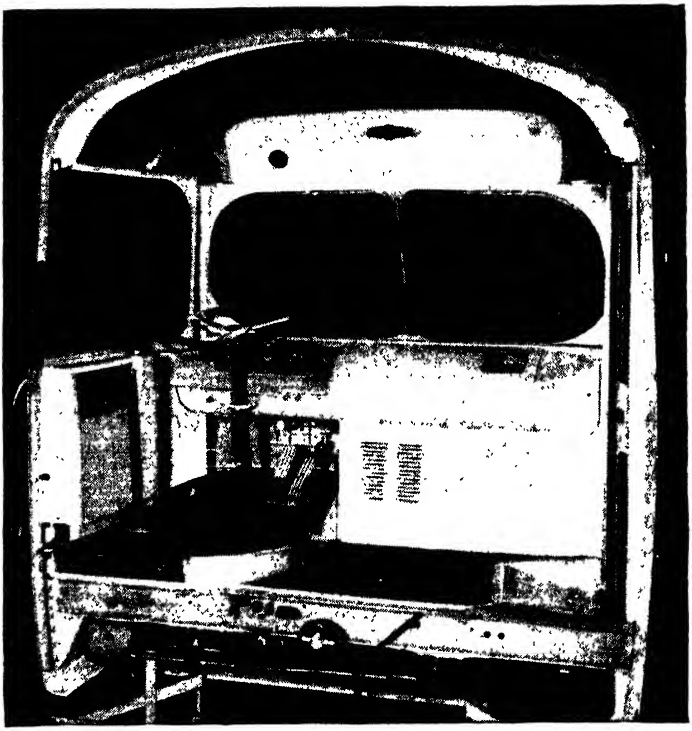


FIG. 12:7. Front vestibule assembly for modern motor bus. This typifies the nature of completed major assemblies joined by relatively simple final assembly operations to produce a completed end item. Manufacturing planning of this type is the keystone of mass production. (*Courtesy of The Nashville Corporation.*)

ASSEMBLY INSPECTION FOR CONTINUOUS-FLOW PRODUCTION

When the production plan involves a continuous flow of a large quantity of identical items, it is not customary to issue separate records for individual items. Reference data, such as an assembly station list, may be issued to establish the work required at each assembly station; but it is unlikely that individual Inspection acceptance records will be maintained.

In this case Inspection records are usually limited to an *inspec-*

tion-flow record, showing the quantities of assemblies accepted, reworked, and rejected by each inspector during his shift. Inspection acceptance and rejection stamps are applied to assemblies in the usual manner. Acceptance and rejection tags can be used to

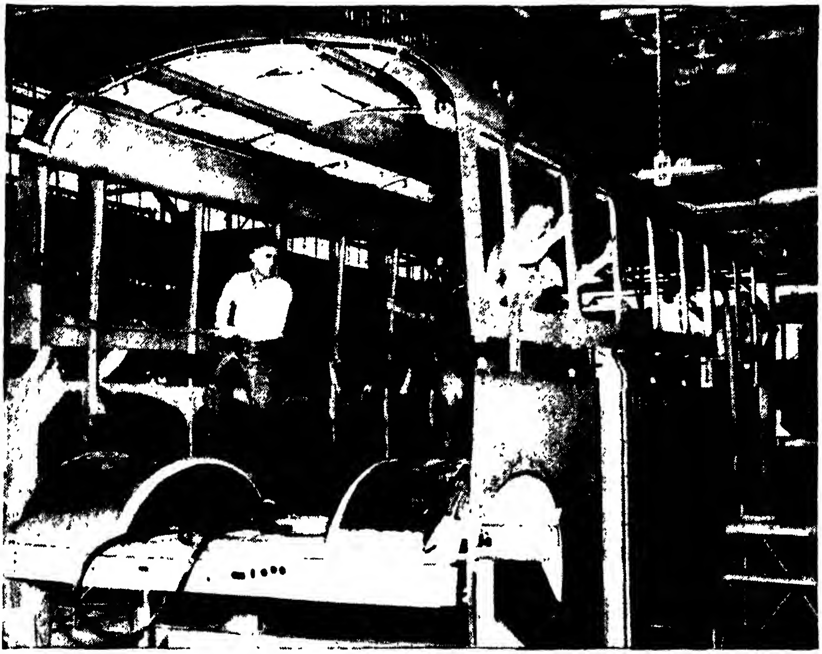


FIG. 12:8. The operation of mating the mid-body upper and lower subassemblies in the first operation in final assembly of a modern motor bus. (*Courtesy of The Nashville Corporation.*)

identify groups of items (or individual items, in the case of rejections) when size or some other condition does not permit stamping.

INSPECTION ACTION ON ASSEMBLIES

Basic procedures for assembly inspection are identical with those followed during fabrication inspection. Accepted items are marked with an Inspection acceptance stamp. Items returned for rework are accompanied by a rework tag, noting the nature of the work that must be accomplished to make them acceptable, or they are noted on the *inspection squawk sheet*—except that items

that must be reworked by some group other than the one presenting them to Inspection should be handled on a rejection notice rather than on a rework tag. All rejected items are identified by rejection notices and are sent to the salvage accumulation area in the case of small assemblies. Large rejected assemblies are not ordinarily forwarded to the salvage accumulation area but are instead surveyed on the spot, and a disposition of them is there determined.

A record of deficiencies found by Inspection must be maintained for all major and final assembly operations. The *assembly unsatisfactory report* (often referred to as an "inspection squawk sheet"), shown in Fig. 6:2, is one means of accomplishing this end. Upon Inspection's discovering the first unsatisfactory condition on a given assembly, the squawk sheet is originated, and it remains in the inspection log for the end item at all times. As each unsatisfactory condition is remedied, it is signed off by Inspection through application of an acceptance stamp opposite the proper item. This record shows at all times the work that must be corrected to produce an assembly acceptable to Inspection. Final acceptance of an end item is not granted until all complaints on the squawk sheet are satisfactorily remedied.

Assembly-inspection Procedure

It is not feasible to discuss all detail procedures that may be accomplished by Inspection, for these will vary greatly with the nature of the end item. However, the following basic steps must be accomplished for practically any assembly, and are indicative of the general nature of assembly-inspection examinations.

1. Drawing prints relating to the assembly should be examined for
   a. Items required to produce the assembly.
   b. Finish and other specifications that must be followed.
   c. Notes relating to special assembly procedures.
   d. Advance engineering information.
2. All items forming the assembly should be checked for Inspection acceptance stamps.
3. Movable items should be checked for freedom of operation, lack of interference, and presence of proper lubricants.
4. Workmanship of all items should meet quality standards.

5. All required items should be in the assembly, properly and securely attached, and with all necessary safety wire, lock washers, and cotter keys installed.
6. All rivets and bolts should be tight, except those bolts that must be loose to permit movement of certain items.
7. Lubricator fittings should be checked for accessibility.
8. All electrical and plumbing lines should be checked for possibility of chafing against the assembly structure.
9. Self-locking nuts should be checked for proper thread engagement and used only where the bolt is not subject to torque during operation of the end item.
10. All adjustments should be checked for proper settings.

FINAL-ASSEMBLY INSPECTION AND TEST

Upon completion of all assembly and installation work required to construct a given end item there is need for certain final-assembly inspection and test, to make certain that it operates satisfactorily and can safely be delivered to the customer. The detail nature of this examination will be governed by the nature of the end item, but in general it involves review of previous inspections shown in the inspection log, specific sampling inspection, and definite operational tests.

Sampling inspection, in the nature of reinspection of critical installations and adjustments, may be considered desirable, in addition to an established routine of operational inspection to verify that the completed end item meets all performance requirements. This final inspection is most important from the consideration of customer satisfaction and should not be left to chance. Instead, detailed inspection instructions should be prepared, listing the proper sequence of investigation during all inspection and operational testing work and establishing permissible limits on all operational checks. The results of these investigations should be recorded on the applicable inspection operation lists and squawk sheets.

INSPECTION RESPONSIBILITY FOR SERIAL NUMBERS

Many end items involve purchased components, such as generators, instruments, and the like, that bear serial numbers established by their respective manufacturers. It is vitally important,

from the viewpoint of handling possible future customer complaints on unsatisfactory operation or orders for spare parts, that a record be maintained of the identity of all serialized components relating to each end item.

It is normally a responsibility of Inspection to maintain a suitable record of all serialized components in each end item, through the medium of the inspection log. A serial-number record should form a part of the log on each end item and should list information regarding the disposition of each serialized component. In some cases it is desirable to prepare this record in duplicate—one copy remaining in the inspection log and the other being forwarded to the customer service department for their information, and posting to records maintained for each end item.

FINAL-ASSEMBLY REJECTIONS

In the case of a large end item it is obviously impractical to forward a rejected final assembly (and major assemblies as well) to a salvage accumulation area for review. Instead, the rejection notice is forwarded to the salvage committee in the usual manner, *but the item remains in the final-assembly area.*

Rarely is a complete final assembly rejected. Ordinarily the rejection relates to some particular subassembly or installation. The defect is surveyed by the salvage committee while the item is still in the final-assembly area, and the defect is disposed of either by being accepted as a deviation, rework, or special repair, or by replacement of the defective portion.

QUANTITY VARIATIONS

When actual quantity of detail items or assemblies is found to be at variance with the value shown on the shop or assembly order, it is normal practice for Inspection to investigate only large or unusual variations. In these cases the production-control department is notified, and it, in turn, attempts to locate the missing items. Meanwhile, the lot is held by Inspection until Production Control either forwards the missing items or notifies Inspection that these cannot be found.

The most important feature in connection with variations in item quantities is that Inspection makes a count as the first step

in beginning the examination and immediately notes the result upon the shop order or upon some other paper accompanying the items. Otherwise, Inspection may be held liable for the shortage.

STATISTICAL QUALITY CONTROL

When failure of a particular item may result in serious injury or death, there is scarcely any acceptable substitute for 100 per cent inspection of each and every item. Instances where such close inspection is mandatory are found in aircraft primary structure and power plants, and in certain pressure vessels, elevators, and the like. In other cases the cost of a failure may be so great that the expense of 100 per cent inspection is well justified; this is true of certain oil-well drilling equipment.

When a small possibility of failure may be tolerated and will not result in serious injury or death to personnel or in serious financial loss, the application of sampling inspection is worthy of investigation. When this form of inspection is employed, less than 100 per cent of the articles are inspected, and *successful application is possible when the samples are based on adequate statistical data with accurately determined maximum limits for defects within samples.* This method of scientific sampling inspection, often referred to as "statistical quality control," is especially adaptable to fabrication inspection and may be applied in the following manner.[3]

The basis of the inspection control is a simple 4- by 5-in. card. One is kept at each machine or operation normally subject to patrol inspection, usually in a metal holder on the machine or over the bench. On the card is written the basic record of inspection action at each periodic inspection visit. All the cards in a department are collected by the inspector at shift's end, summarized, and turned in to the inspection office.

On the card (Fig. 12:9), the letters *SS* refer to sample size, which is generally predetermined and printed on the card, becoming in effect instructions to the inspector. The sample, of course, is random, but the inspector exercises care to be sure that it represents only the work done at the machine since his last visit.

The letter *d* is the number of defective pieces found in the sample, if

[3] Extracted from C. W. Kennedy, "Simple Statistical Control in Patrol Inspection," *Factory Management and Maintenance*, November, 1948, pp. 108–110.

there are any. Defectiveness includes any valid reason why the work does not conform to specifications or shop standards and practices.

At the end of the shift, the inspector adds up the *SS* and *d* columns. Either he or a clerk in the office calculates the per cent defective by dividing the total number of defective pieces found by the total number

PATROL INSPECTION REPORT

PART NO.	ORDER NO.	DEPT.
117H-2903	216	A14

MACHINE NO.	OPERATOR
B&S 2B	4-127

TIME	SS	d	DISPOSITION
7:35	10	0	OK
8:20	10	0	OK
9:50	10	1	Tool Marks
11:00	10	0	OK
12:45	10	1	486 dim.
1:45	10	2	shut down
2:15	10	1	Reset on .486 dim.
2:45	10	0	OK
	10		
TOTAL	80	5	DATE 6-17
PER CENT DEFECTIVE	6%		SIGNED J. J. S INSPECTOR

FIG. 12:9. Random samples of 10 each are checked by inspector and recorded on this card. Defects exceeding 4 per cent signal shutdown.

of pieces actually examined (d/SS = per cent defective). Decimal places are disregarded; per cent defective to the nearest half per cent is sufficient. . . .

Now enters the . . . statistical quality control application. A simple chart prepared on ordinary ¼-in. cross-section or graph paper, also is hung on the machine. Figure 12:10 shows a section of this chart, on which the inspector has plotted the daily percentages defective.

It can be seen at once that the chart presents a picture . . . of how the job is going in respect to quality. Almost inevitably, simply dis-

playing a chart of this type seems to bring about improvement in scrap and rework and thereafter keeps it at a reasonable minimum. The evidence shows that by the fourth and fifth week the charted points (most of them, at least) are . . . along the zero line.

During the course of a day the inspector may have examined a total of 80 pieces—10 at a time—but the machine may have produced, say, 500 pieces. It is reasonable to presume that if he has uncovered a few defective pieces in the sample, more defective work exists in the main

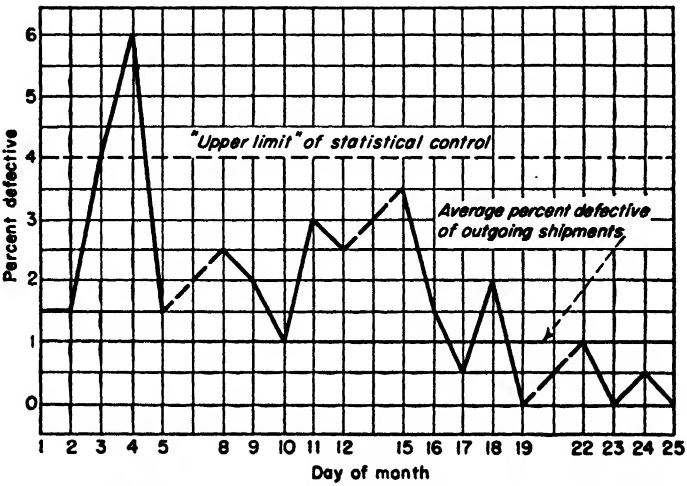


FIG. 12:10. Percentage defective is calculated daily. Result is posted daily to control chart at each machine.

batch of work. Experience shows, in fact, that even though no defects at all appear in the sample, they can still be present but undiscovered in the work the sample comes from. Or, all the defects in the lot may have turned up in the sample.

These conditions result from the "accident of sampling." And here is where the mathematician comes in. He is able to calculate the probable error in sampling.

The chart emphasizes the 1 per cent figure. Put as briefly as possible, it is anticipated the machine may allowably produce as much as 1 per cent defective or substandard pieces. On the whole, it is uneconomic . . . to require a machine to produce perfect work. The average industrial allowance is 1 per cent. However the figure can be set higher or lower, depending upon practical commercial requirements or the type of equipment.

On the chart, also, is a horizontal dotted line at 4 per cent. This is

known in statistical quality control as the *upper limit* for sampling error. Any point plotted on the chart represents the per cent of defective work appearing in samples only. So, the mathematician tells us—looking at the chart as a whole—that when any point falls between the base and 4 per cent line, the actual work that the sample represents, very probably, contains about 1 per cent defective pieces. Because of the accident or error of sampling this will be true even though the results of sampling may put the point on the base line, or as high as 3¾ per cent.

Where the per cent defective in the day's samples turns out to be *greater than 4 per cent*—more than the upper control limit for the so-called sampling error—something more than the accident of sampling has entered the picture and the work represented by the sample is more than 1 per cent defective.

The practical effect on supervision is that, so long as the daily dots appear under the 4 per cent line, there is little need for worrying about the machine or operator. However, when points appear on the 4 per cent line or above it . . . then some sort of investigation is necessary. Also the work done during these . . . . days is segregated and sorted over, reworked, or salvaged.

There is one more point of value in connection with the statistical system added to patrol inspection. When an inspector is making his rounds he is continually beset with the necessity for deciding whether to shut a machine down or let it run for a while longer—even though he may have found one or two defectives in the sample.

Assume that he will average seven, eight, or nine rounds per day, that he will have examined by the day's end somewhere between 70 and 90 pieces. Four per cent of 80 (± 10) is, in round numbers, 3 pieces. [Three pieces], then, is the upper limit of sampling error. If, at any time of the day, the accumulation of defectives reaches 3, as shown on the inspection record card, the machine should be shut down. The reason, of course, is that if the machine is allowed to continue unchanged, more defectives will probably show up in subsequent samples, and a complete inspection of the day's work stands a [good] chance of uncovering more than the allowed 1 per cent defectives.

Determination of the allowable upper limit involves precise statistical analysis and mathematical calculation. For a comprehensive treatment of the mathematics of statistical quality control, the reader is referred to "Statistical Quality Control" by E. L. Grant.[4]

[4] McGraw-Hill Book Company, Inc., New York, 1946.

CHAPTER 13
SALVAGE

An important function of the inspection activity of an industrial plant is assisting in utilizing material and parts that are not in conformance with governing specifications. The problem is simple when nonconforming items deviate in a manner that permits reworking to bring them within established limits. When rework cannot be accomplished without deviating from specifications or drawings, the problem becomes more complicated and can be satisfactorily handled only through a well-organized, systematic *salvage* [1] procedure.

When the inspection function is properly organized, all rejected items are reviewed first by the rejecting inspector, to ascertain whether it is possible to rework them to within allowable limits without affecting the appearance or integrity of the finished item. If this can be done, the offending items are returned to the submitting department for rework. If the nature of the deficiency is such that either a repair or *special rework* will be required, the corrected item will deviate from governing specifications, and salvage action is required. In these cases the item should be forwarded by the rejecting inspector to a salvage board for disposition.

Centralized control by a salvage board is desirable, as the final disposition of rejected items involves departments other than Inspection. A basic plan for handling salvage requires that all rejected items not possible of rework to allowable limits be (1) identified by the rejecting inspector; (2) recorded; (3) withdrawn from the production flow; (4) securely stored, to prevent unauthorized usage; (5) reviewed by a salvage board comprising

[1] Salvage is sometimes referred to as "material review." However, the identical functions are involved in each case, regardless of nomenclature, and it is considered that *salvage* more properly describes the action taken.

representatives of all affected departments; (6) assigned a final disposition; (7) promptly salvaged or scrapped; (8) identified and recorded, until either used as salvage or disposed of as scrap; (9) reported to Production Control, to permit reordering of scrapped parts; and (10) thoroughly investigated (and corrective action taken) in cases of chronic rejections.

HANDLING OF REJECTED ITEMS

When an inspector finds an item that is not within specification limits, there are two—and only two—available courses of action. If the item is reworkable to limits, it should be returned to the shop for rework. If not reworkable, it must be rejected and withdrawn from the production flow.

For the item to be reworkable, it must be possible to complete its fabrication or assembly in a manner that produces an item in accordance with requirements without resorting to operations not shown or described by the specifications. For instance, a simple case is a shaft turned to a specified diameter. If the o.d. is oversize, the shaft can be returned for rework; if undersize, the shaft cannot be reworked and must be rejected. Salvage action will then be required, even though the rejecting inspector may know that the part can be salvaged by applying hard-chrome plate to increase the o.d. to above the minimum limit.

Responsibility for determining disposition of rejected items should never be decentralized and made available to each inspector. Neither should authority to scrap material be given to each inspector. The basic purpose of salvage action is utilizing every possible incorrectly manufactured item, without jeopardizing the integrity of the end product. This can be economically and *safely* accomplished only by personnel thoroughly experienced in salvage methods and familiar with minimum acceptable strength and performance requirements. Satisfactory handling of salvage not only involves Inspection, but also concerns engineering, production, and purchasing functions.

Upon an inspector's determining that a certain item (or group of items) must be rejected, action should be taken to identify the items, to prevent accidental usage prior to salvage action, to record the rejection, to notify all parties concerned, and to for-

ward the rejection to the salvage area for safekeeping, pending review by the salvage board.

All rejected items should be individually stamped with a rejection symbol (see Chap. 2) and be tagged with the *rejection notice.* The stamping will tend to prevent accidental usage, as it provides immediate identification of rejected items. Small parts, for which stamping is not practicable, should be placed in a sealed envelope, box, or other receptacle, with the rejection notice affixed to the container.

REJECTION NOTICE PROCEDURE

A *rejection notice* (see Fig. 13:1) should be prepared for each rejection, and copies should be sent to all parties affected. Rejections, even though they may be eventually salvaged, interfere with production schedules and may cause production shortages. Copies of the rejection notice should be sent to the production-control department, as well as to the salvage board. In the case of rejected purchased items, it is also necessary to notify the purchasing department, in order that the vendor may be informed, that necessary supplementary purchase orders may be issued, and that Purchasing may have a voice in the final disposition made by the salvage board. With some government contracts it is necessary to notify the customer's representative regarding each and every rejected item.

Rarely can sufficient copies of the rejection notice be prepared from a carbon-copy type form, and a reproducible form must be employed. It is desirable to use a rejection notice prepared as a hectograph master, with a hard copy (produced as a carbon copy of the master) for attachment to the rejected item, similar to that shown in Fig. 13:1. This form provides for identifying the rejected item, gives the reason for rejection, and records the salvage board's disposition.

The rejecting inspector enters information regarding identification and the reason for rejection, attaches the hard copy to the rejection, and forwards the rejected item to the salvage accumulation area. The original (hectograph master) copy of the rejection notice is forwarded to the Inspection office for duplication of copies. Inspection files, Production Control, Accounting, the sal-

vage board, and (in some cases) the customer's representative receive copies. In cases of rejection of a purchased item, a copy is sent also to the buyer affected. After duplication of copies, the original is forwarded to the salvage board for addition of data regarding disposition of the rejected item.

In a large plant, the forwarding of rejected items and the hectograph masters of the rejection notice will be handled by an inspection dispatcher. In a smaller organization, it should be the responsibility of the rejecting inspector to deliver rejections to the salvage area, and rejection notices to the Inspection office. Rejected large assemblies, which are not practicable of movement to the salvage area, should be left at their location in the shop, and the salvage board's members should visit the factory area to determine disposition.

TYPICAL REJECTION NOTICE

In Fig. 13:1 is shown a typical Inspection rejection notice. This is prepared as an 8½- by 11-in. form, comprising a hectograph-master original and a carbon copy on heavy tag stock. After the required information has been entered, the two parts are separated; the "hard copy" is attached to the rejection and the hectograph master is sent to the Inspection office, for the production of copies for distribution to all parties concerned. This form provides the following information:

Date. Date of rejection

Part Name. Name of rejected item

Vendor. Filled in with name of supplier, if a purchased item

Part No. Drawing or part number of rejected item

Assembly No. Drawing or part number of next assembly of rejected item

Purchase Order No. Used only for receiving-inspection rejections

Receiving Report No. Used only for receiving-inspection rejections

Order No. Shop or assembly-order number pertaining to rejection

Release No. Release or lot number pertaining to rejection. Obtained from shop or assembly order

Serial No. Serial number of end item affected when rejection occurs in final assembly—or may be serial number of major component, or of purchased item

REJECTION NOTICE

Nº 5123

DATE

PART NAME				VENDOR	
PART NO.	ASSEMBLY NO.			PURCHASE ORDER NO.	RECEIVING REPORT NO.
ORDER NO.	RELEASE NO.	SERIAL NO.		MODEL	DEPT RESPONSIBLE
QUANTITY REJECTED	QUANTITY ACCEPTED	DEPT	BLDG	LOCATION OF REJECTED PARTS	TOOLING CHECK REQUESTED

REASON FOR REJECTION:

INSPECTOR'S SIGNATURE	APPROVAL SIGNATURE

SALVAGE BOARD ACTION

DEVIATION	O.K.	REWORK	REPAIR	RETURN TO VENDOR	SCRAP
QUAN	QUAN	QUAN	QUAN	QUAN	QUAN

INSTRUCTIONS:

PROD APPR & DATE	INSP APPR & DATE	ENG APPR & DATE	PURCH APPR & DATE	CUST APPR & DATE

COPIES TO DEPT ⟶ STORES SIGNATURE

REWORK SATISFACTORILY COMPLETED	INSP ACCEPT & DATE	CUST ACCEPT DATE	REMARKS

FIG. 13:1. Inspection rejection notice.

Model. End-item model for which rejected item was intended

Department Responsible. Filled out by rejecting inspector when able to determine responsibility; otherwise, left blank and completed by salvage board

Quantity Rejected. Quantity of items rejected from lot submitted to inspector

Quantity Accepted. Quantity of items accepted from lot submitted to inspector

Department. Department submitting the lot in which the rejections were found

Building. Used when company operations are in more than one building

Location of Rejected Parts. Exact location of rejection. This is especially important in the case of assemblies which are too large to be

forwarded to the salvage area, and which must be reviewed at the point of rejection

Tooling Check Requested. Used when rejecting inspector believes the difficulty due to defective tooling

Reason for Rejection. Description and sketches used as necessary fully to describe the basis for rejection. The rejection inspector is responsible for the item's being in strict conformance to specifications, except as listed herein. The salvage board are not responsible for reinspecting the entire item, only for reviewing the variations listed on the rejection notice

Inspector's Signature. Signature of rejecting inspector

Approval Signature. Signature of rejecting inspector's supervisor

Salvage Board Action. Filled in by the salvage board after they have completed their review of the rejection and provided information for disposition of the rejected items

Deviation. Quantity of rejected items considered acceptable as a "deviation" by salvage board

O.K. Quantity of items found to have been unjustifiably rejected

Rework. Quantity of rejected items to be reworked in accordance with salvage board's instructions

Repair. Quantity of rejected items to be repaired in accordance with salvage board's instructions

Return to Vendor. Applicable only to receiving-inspection rejections, or when defect in purchased item is discovered in a factory department during assembly. Requires approval of Purchasing

Scrap. Quantity of rejected items scrapped by salvage board

Instructions. Detail instructions regarding allowed deviation, rework, or repair. When the rejection notice does not provide sufficient space, an engineering order (or similar advance engineering-information document) can be normally prepared and referenced in the "instructions" space

Prod. Appr. and Date. Signature and date by Manufacturing Planning's representative on salvage board, signifying that rework or repair is considered practicable and economical

Insp. Appr. and Date. Signature and date by company Inspection representative on salvage board, signifying approval of action

Engr. Appr. and Date. Signature and date by Engineering representative on salvage board, signifying approval of action

Purch. Appr. and Date. Signature and date by Purchasing representative on salvage board; required only for disposition of rejected purchased items

Cust. Appr. and Date. Signature and date by customer representative on salvage board; used only when customer approval of salvage is required

Copies to Department. Quantity of copies to be sent each of the indicated departments; filled in prior to duplicating copies in accordance with an established schedule for various models and types of rejections

Store's Signature. Signature and date by storekeeper upon receiving rejected items accepted by the salvage board, prior to detaching hard copy and forwarding to Inspection office

Rework Satisfactorily Completed. Filled in by the inspector accepting items after satisfactory accomplishment of approved rework or repair

Insp. Accept. and Date. Acceptance stamp and date by accepting company inspector

Cust. Accept. and Date. Acceptance stamp (or signature) and date by customer inspector, if required

Remarks. Remarks pertinent to rework or repair, such as notation of a portion of the items being spoiled and rejected again

SALVAGE AREA

Rejected items constitute a hazard because of the possibility of accidental usage of them in manufacturing operations. For this reason a separate area should be designated for the storage of all rejected items, and they should remain therein until reviewed and disposed of by salvage-board action. Scrapped items should be promptly mutilated to preclude the possibility of accidental usage and removed from the factory premises as soon as possible.

The salvage area should be enclosed and locked, with facilities for storage and inspection. Only members of the salvage board should be permitted access to this area, and company rules should establish discharge as the possible penalty for unauthorized entry into the salvage area. Rigid control of rejected items is important, even in cases in which integrity of the end item may not affect life or property; for in all cases delivery of defective products will adversely affect the reputation of the manufacturer and will jeopardize future sales.

SALVAGE BOARD

Salvage disposition involves decisions beyond the control of Inspection in cases of deviation, special rework, or repair; as Inspection's responsibility involves only determination that items are within allowable specification limits. To determine disposition of salvage items, it is necessary to apply the collective knowledge of Inspection, Manufacturing Planning, and Engineering. In the case of purchased items, it is also necessary to consult with Purchasing. When the item is being manufactured under contract to a government agency, it may be necessary to obtain approval of the customer's representative for all salvage disposition.

It is apparent that minimum requirements for a salvage board are one representative each from Inspection, Manufacturing Planning, Engineering, and Purchasing. The salvage board should be established as a formal group, with prime and alternate representatives from each function, and should hold regularly scheduled meetings. In the case of a large plant, these may be daily, although weekly meetings are usually sufficient for a small operation. Special meetings may be called at any time by the Manufacturing Planning representative, to dispose of items likely to cause a critical shortage.

Duties of Salvage Board

Each member of the salvage board has clearly definable duties and responsibilities. The Inspection representative has final authority to scrap items submitted for salvage action, even though other board members may consider the items acceptable. This arrangement is necessary if Inspection is expected to assume full responsibility for product integrity.

The Engineering representative must authorize all salvage acceptance and approve repair and rework methods. In cases involving complicated repair methods, it is Engineering's responsibility to prepare the necessary special-repair drawings or "advance engineering information," to guide the shop in accomplishing the work. All repair drawings and orders must be referenced on the rejection notice, and become a part of the notice.

The Manufacturing Planning representative determines the

practicability of accomplishing planned rework or repair and advises regarding their economy. In some cases the cost of a repair or rework is more than the rejection's value, and it is more economical to scrap, even though salvage is possible. On the other hand, the item may be needed to relieve a critical production shortage, and salvage action is desirable even though its cost is higher than the rejection's actual value.

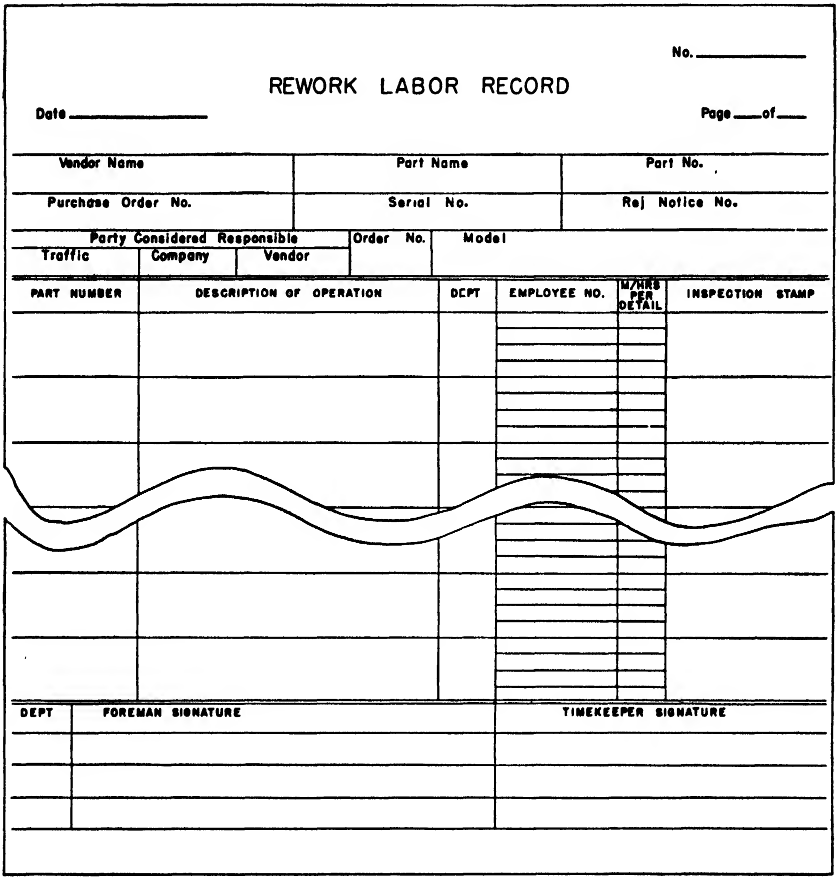
Purchasing has an important part in the case of receiving rejections, as these involve vendors with whom Purchasing is in direct contact. The Purchasing representative is most familiar with delivery schedules and with agreements between company and vendors. In the case of purchased-item rejections, it is necessary to determine the relative wisdom of returning the item to the vendor or reworking or repairing it at the company, to be followed by billing the vendor for the extra work. Factors to be considered are the delay resulting from returning the item to the vendor and the vendor's contractual responsibility. In other cases purchased items may be damaged through negligence of company personnel, and it must be determined whether it is more economical to return the item to the vendor for repair, to accomplish repair at the company, or to scrap. The assistance of Purchasing often is necessary in reaching a decision.

When it is desired to accumulate accurate costs of salvage repair or rework on a certain rejection, a *rework labor record,* similar to that shown in Fig. 13:2, can be originated by the salvage board and attached to the rejection notice hard copy. Actual time expended is entered by the departments accomplishing the work. Upon completion of the necessary work and its acceptance by Inspection, the completed rework labor record is forwarded to Accounting. Ordinarily this record is required only in cases in which it is intended to bill a vendor for rework or repair of defective purchased items.

Salvage-board Action

At each meeting of the board, all items awaiting salvage action are examined, a decision is reached, and the corresponding rejection notice is completed, with information regarding the action decided upon. In each case the final action must be (1) to accept as O.K., (2) to accept as deviation, (3) to accept as special re-

work; (4) to accept as special repair, or (5) to scrap. All members of the salvage board must agree to the item's being acceptable. A majority decision is not satisfactory, and the final ac-



No.
REWORK LABOR RECORD
Date
Page of

Vendor Name	Part Name	Part No.
Purchase Order No.	Serial No.	Rej Notice No.

Party Considered Responsible			Order No.	Model
Traffic	Company	Vendor		

PART NUMBER	DESCRIPTION OF OPERATION	DEPT	EMPLOYEE NO.	M/HRS PER DETAIL	INSPECTION STAMP

DEPT	FOREMAN SIGNATURE	TIMEKEEPER SIGNATURE

Fig. 13:2. Rework labor record.

ceptance decision should be unanimous in all cases. Following the establishment of a decision and the completion of the rejection notice, the item is routed out of the salvage area for the required action.

Items accepted as "O.K." are those which the salvage board finds to have been unjustifiably rejected. The disposition instruction in such a case is "Rejection canceled."

Items accepted as deviations are those which the salvage board decides can be used "as is," despite their not being within specification limits. This can often be tolerated, for in many cases dimensional limits specified on drawings are not the absolute usable limits, but rather are practicable values. In fact, this often is considered good engineering practice, for while dimensional limits should be as "loose" as practicable, it is often unwise to specify absolute maximum limits. Then practically all parts manufactured beyond limits require special rework or will be scrap. When limits are below absolute maximum, some improperly manufactured items can be accepted as deviations.

Items not acceptable as deviations can be used only after accomplishment of special rework or repair. Special rework will be required for improperly manufactured items. Repair will be needed by items damaged during the manufacturing process. The rejection notice salvage instructions should clearly indicate the nature of the action taken (deviation, rework, or repair) to permit proper recording and execution of salvage action.

FINAL DISPOSITION OF SALVAGE ITEMS

The rejection notice must be filled in with suitable information regarding the disposition of each rejection, and the rejection must be forwarded with the hard copy for accomplishment of the required action. When the action is accepted as a deviation, the items are identified at that time with a salvage acceptance stamp, placed adjacent to the existing salvage withholding stamp. Hectograph copies of the rejection notice (showing disposition action) are sent to all recipients of the original notice of rejection.

When a multiple disposition occurs, the items not requiring repair or rework can be released immediately through issuance of another rejection notice for record purposes by the salvage board.

Items disposed of as scrap are identified with the scrap stamp, prior to release from the salvage area, and should be mutilated in a manner that precludes accidental usage, *followed by prompt removal from the factory premises.* This is important, for nothing can be more embarrassing to Inspection than to have scrap parts discovered during final-assembly inspection of the completed end item. Hectograph copies of the rejection notice

scrap order are forwarded at this time to all recipients of the original notice of rejection. If only part of the items are scrapped, another rejection notice should be originated by the salvage board to record this action, and the original notice should be retained to identify the usable items.

Scrapped assemblies should be stripped of all usable detail parts and subassemblies, in cases where the cost of removal will not exceed their value. Actual removal of these usable items is not a normal function of the salvage committee, and it can best be handled by noting the parts to be removed on the scrap order, to be accomplished by Production Control's routing the scrapped assembly to a conservation function prior to actual delivery to the scrap accumulation area. The removed items should be reinspected prior to being returned to stores.

Rework and repair items are routed to the proper department for accomplishment of the work described on the rejection notice, and the hard copy of the notice is returned to salvage-board records through the Inspection office, after acceptance of the items following rework or repair. Upon the work's being properly accomplished, all items (and the rejection notice) are identified with the salvage acceptance stamp and are reinstated for production usage. If the work is not acceptable, the disposition will be either to return for additional rework, or to scrap—more likely, the latter.

SALVAGE RECORDS

The most important salvage record is the rejection notice, used to reject unsatisfactory items. The original copy of the notice is used to reproduce required copies for distribution at the time of rejection, and again when final salvage disposition is accomplished. The hard copy serves as a traveler, to accompany the rejection to the salvage accumulation area or to shop departments for accomplishment of repair or rework, and it is not detached until the salvaged items are received in the parts stockroom (or scrap accumulation area) after completion of salvage action. After its removal, the hard copy is forwarded to the Inspection office for matching with the original copy in the salvage completion file, and thence to the salvage board.

Records should also be maintained of all rejections by part number, to determine the occurrence of chronic rejections. In such cases a detail investigation should be made by the quality-control engineer, and corrective action should be initiated. Inspection's function is not only to reject defective items, but also to determine the cause of chronic defects and develop methods for their elimination. This action includes investigation of manufacturing processes and observation of work accomplished by outside-production sources, to make certain that proper processes, workmanship standards, and specifications are observed.

SALVAGE BOARD DAILY REPORT

Date ________ Shift ________

Location ________

Part Number	Reject Notice No.	Salv Insp	Dept Respon	Quantity					Remarks
				O.K.	DEV	REW	REP	SCRAP	
			Totals						

Fig. 13:3. Salvage-board daily report.

In Fig. 13:3 is shown a *salvage-board daily report* that can be used to accumulate data on chronic rejections. This provides for the following information:

Date. Date of report
Shift. Work shift to which report relates
Location. Used when more than one salvage-accumulation area exists
Part Number. Part number appearing on rejection notice
Rejection Notice No. Serial number appearing on rejection notice
Salv. Insp. Inspector approving salvage-disposition action
Dept. Respon. Manufacturing department, carrier, or vendor considered by the salvage board to be responsible for the rejection
Quantity. In these columns are entered the quantities of items in each rejection disposed of as O.K. or improperly rejected, "deviation," "rework," "repair," or "scrap"
Remarks. In this space is entered special information considered pertinent by the salvage inspector

This report is prepared each day by the salvage inspector in charge at each salvage accumulation area and is forwarded to the Inspection office. When salvage action is accomplished on the second and third work shifts, a separate report should be prepared by each shift.

Monthly summary reports of rejections and dispositions should be prepared by the Inspection office and furnished to top management as an indication of the effectiveness of salvage action. When proper salvage control is exercised, it often will be found that over 50 per cent of rejections are salvaged and returned to a usable status.

STANDARD REPAIRS AND MINOR DISCREPANCIES

A great deal of time and effort can be saved by issuance of a *standard-repair manual,* for use by company inspectors, listing rework and repair methods for common shop errors that have been agreed upon by Engineering, Inspection, and other parties concerned. A great deal of salvage-board work can then be avoided, as inspectors in shop departments can issue a rework order instructing the shop to accomplish work in accordance with a certain standard repair method. Thus issuance of a rejection notice is avoided.

Another means of relieving the salvage board of unnecessary work is the *minor-discrepancy report,* to record minor repairs that do not affect structural integrity or performance of the end item. It is necessary only that a record be maintained of each minor discrepancy, with the corrective action applied to each approved by the rejecting inspector and a designated Engineering representative, and actual rejection for salvage-board action is avoided.

Usage of the minor-discrepancy report is normally confined to assembly inspection. Application of this procedure to fabrication inspection might lead to complications during subsequent examinations made by assembly inspectors, unless an unjustifiably complicated system of identifying "discrepancy" detail items is inaugurated.

Establishment and usage of standard-repair manuals and minor-discrepancy reports are outlined in Chaps. 5 and 6.

APPLICATION OF SALVAGE PROCEDURE

The salvage procedure outlined in this chapter has considered all possible applications, and provides satisfactory control for the most precise form of end item. It will be observed that the forms and basic procedures provide the following controls:

1. The rejection notice provides copies for identifying the rejection, for the Inspection office to record the rejection, and duplicate copies for all parties concerned.
2. A copy of each rejection notice can be placed in a follow-up file in the Inspection office. This can be arranged on a date basis, to insure that all rejections will be processed within a stipulated time.
3. A copy of each rejection notice can be placed in a follow-up file in the salvage-board records, and if the rejected items do not reach the salvage area within 24 hr an immediate search can be made.
4. Upon determination of disposition by the salvage board, this is entered on the rejection notice original and copies are again duplicated and sent to all parties concerned, insuring prompt and complete notification on all rejections.
5. A copy of each rejection notice disposition can be matched with the original notice of rejection by Inspection office and salvage board, and be placed in an "active" file, to await receipt of the hard copy after completion of the required action. If this is not received within a reasonable time, an investigation can be made to determine the cause.

Additional safeguards against the possibility of "lost" rejections or rejection notices are provided by the following procedures:

6. The *inspection daily-flow record* (see Chap. 2) lists all rejections and corresponding rejection notice serial numbers. A follow-up sheet can be placed in the Inspection-office salvage files for each rejection notice shown on the daily-flow records, and an investigation can be made if the original (master) copy of the notice is not promptly received.
7. All items accepted after accomplishment of salvage repair or rework are also recorded on the inspection daily-flow record. If the corresponding hard copy is not received by the Inspection office within a reasonable time, an investigation can be made.

8. The *salvage-board daily report* lists the serial numbers of all rejection notices processed each day. If the corresponding original copies are not promptly received by the Inspection office, an investigation can be made.

Each inspection department should develop detailed salvage procedure to provide required control without involving undue expense, and without jeopardizing the integrity of the end item. Little emphasis has been given herein to detailed procedures, as these will vary with the company and the nature of the end item. Instead, emphasis has been placed upon fundamental requirements, suitable specimen forms, and basic methods of processing and controlling rejections.

CHAPTER 14
SHIPPING

After the end item is completely assembled and tested, it is normally forwarded to a stockroom to await shipment to the customer or, when manufactured on a special order, may be sent directly to Shipping. Inspection has guarded the product's quality throughout the production cycle of receiving, fabrication, assembly, and final test. In the case of end items packaged immediately after completion of the production cycle, Inspection has observed that the basic packaging was properly accomplished without damage to the contents and that each container is properly marked to identify its contents.

Inspection now has but one remaining obligation—that of making certain that the final preparation for shipment is accurately accomplished, with the proper quantity of the correct items prepared for forwarding, and that each shipment is delivered to the carrier in an undamaged condition. While the primary function of shipping inspection is verifying that the proper items are correctly packed for shipment to customers, a second important responsibility is guarding the quality of all raw-stock material and of semifinished and finished items shipped to outside production sources. This latter duty is important when extensive outside production is purchased by the company, for this means of correcting manufacturing deficiencies will function satisfactorily only when the proper quantity and quality of material is shipped to the outside sources.

DUTIES OF SHIPPING INSPECTION

The basic duty of shipping inspection is insuring that all items forwarded by the company shipping department meet all established quality standards and conform to the description and quan-

tities shown on packing sheets or other instructions. Accomplishment of this duty involves

1. Verifying that all end items are complete, have received final test inspection acceptance, conform to the requirements of the customer's purchase order, are properly packed to avoid damage or deterioration in transit, and are correctly identified and addressed
2. Determining that all spare parts conform to the customer's purchase order and company service department's instructions, are properly packaged to avoid damage in transit, and are correctly identified and addressed
3. Inspecting all raw-stock material shipped to outside production sources to insure conformance with the type and quantities shown on packing sheets or other shipping instructions
4. Verifying that all semifinished and completely fabricated items shipped to outside production sources have received required inspection prior to preparation for shipment and are in conformance with the description and quantities shown on packing sheets or other shipping instructions

In each case shipping inspection will follow one of three basic courses of action. Shipments meeting all requirements will be *accepted.* Those which are found deficient in a manner that permits correction will be *returned for rework.* Shipments, or portions thereof, that cannot be corrected by the shipping department will be *rejected.*

The basic steps required for complete control of shipping inspection are shown in Fig. 14:1. This provides for all the inspection operations necessary for the most precise end item, subject to inspection examination at practically every step of its handling, and it can be modified to suit the quality standard selected for a given product.

GENERAL PROCEDURE

A prime responsibility of shipping inspection is verifying that all articles are complete, in proper operating condition, manufactured in accordance with established quality standards, and crated or packed to insure the shipment's reaching its destination undamaged. Nothing can be more harmful to the reputation of a manufacturer than having his product reach the customer incom-

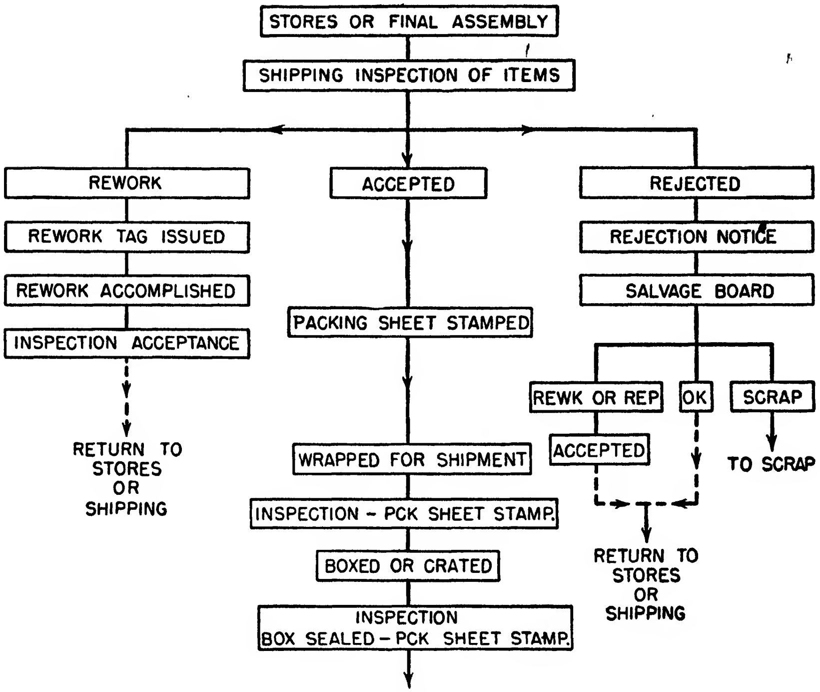


FIG. 14:1. Procedure for shipping inspection.

plete, inoperative, or damaged. Any of these conditions condemns the manufacturer as careless and unreliable.

The basic documents involved with any shipment are the *sales order*,[1] and the *packing sheet*. The former shows exactly what the customer ordered, and the latter shows what is to be shipped. These are normally in agreement in every respect, but there may be cases where less is being shipped than was called for on the sales order, owing to shortages of certain items. These instances should be clearly identified on the packing sheet as being on back order, signifying that shipment will be made at a later date. Unless this is the case, Inspection will be justified in refusing to ac-

[1] The *sales-order* data are based upon information contained in the customer's purchase order, and normally both documents should be in complete agreement. Should the sales-order information appear dubious, Inspection should obtain the original purchase order for comparison.

cept the shipment, on the grounds that not all the items specified on the sales order are included.

The packing sheet should provide columns (for application of inspection stamps) for indicating acceptance both before and after wrapping or packaging of individual articles, and following final packing or crating. These provide for record of Inspection action in examining the articles themselves, in certifying the individual wrapping, and in verifying that final packing and crating have been properly accomplished. Individual stamps should show that each item was acceptable and was properly wrapped, but a single stamp is sufficient for acceptance of each box or crate.

Individual Item Inspection

The items comprising each shipment should be assembled in a designated inspection area when ready for wrapping and packing. Inspection, guided by applicable drawing prints and specifications, should verify that all items are (1) complete; (2) in accordance with workmanship standards; (3) dimensionally correct; (4) properly finished or painted; (5) free from damage; and (6) bearing all required acceptance stamps of preceding inspection, including those of heat-treatment, magnetic-particle inspection, or the like, when these special operations are specified.

Upon the items' being acceptable, the packing sheet should be stamped in the spaces provided, and the shipment be wrapped. Unacceptable items should be rejected for salvage-board action in the normal manner.

Wrapping and Packaging

Following individual inspection, the items are usually wrapped or placed in cartons or similar packages. In some cases of overseas shipments, special moisture-resistant wrapping or preservatives must be applied. In every case it is Inspection's responsibility to see that all wrapping and packaging is accomplished in accordance with company and customer requirements.

At this time the final count is verified, and the shipment is ready for final boxing or crating. Inspection's approval of this step is indicated by stamping in appropriate spaces on the packing sheet. There is normally no need to reject items for salvage

action at this point, for the fault is not with the item but with its packaging. Instead, the inspector should call the unsatisfactory condition to the attention of the Shipping supervisor and should refuse to accept the shipment until suitable correction is made.

Boxing and Crating

After completion of satisfactory wrapping and packaging, the shipment is ready for final boxing or crating and for transfer to a carrier. Inspection should, during this step, verify that the proper items are boxed or crated, that the containers meet all established requirements, that a copy of the packing sheet is placed within (or attached to) the shipment, and that each container is properly marked with address of shipper and customer and with the correct shipment number. Upon verification of these items, the packing sheet should be stamped to show final acceptance, and the shipment is ready for delivery to the carrier. A properly stamped copy of the packing sheet is forwarded to the group responsible for actual delivery to the carrier, as their authority to forward the shipment. Another stamped copy of the packing sheet is forwarded to Inspection office records. In some cases a copy of the Inspection-approved packing sheet must accompany the shipment.

Improper work discovered by Inspection during this phase should not be handled by rejection for salvage action, for again the fault is normally with the packaging rather than with the actual shipment. Instead, acceptance would be withheld until correction action is accomplished. Only in the case of damaged items should rejection occur, and then rejection only of the item rather than of the shipment. Damaged items will normally be replaced by Shipping from stock and the shipment can then be completed.

All items and shipments passing through Shipping Inspection should be recorded on an *inspection flow record* in the usual manner. In some cases a formal *request for inspection* form is used, instead of the packing sheet as a record of Inspection acceptance. This, which is usually produced as a carbon or a hectograph copy of the packing sheet, contains identical information and is used

in the manner outlined herein, except that Inspection acceptance stamps are placed on copies of the "request" rather than on the packing sheet.

SHIPPING FROM STOCK

In many cases packaging takes place immediately after completion of manufacturing, and the packaged items are sent to finished stores, to be shipped at some later date. In these cases inspection of wrapping and packaging is a part of the manufacturing cycle, and the shop order should provide an entry for "wrap" or "package," to be stamped off or otherwise attested by Inspection.

When items to be shipped are drawn out of finished stores wrapped or packaged, the prime responsibility of shipping inspection is making certain that the proper quantities of each are contained in a shipment, that each is free of damage, and that each package *appears* to contain the proper item. As these packages are normally sealed, it is possible to determine only by general examination that the contents are correct, judging by the description and the part number appearing on the outside of the package and by the general surface appearance, weight, or the like, of the container.

SHIPPING DISCREPANCY LIST

When circumstances make such a course desirable, it is feasible to use a *shipping discrepancy list* to accompany each shipment through its processing and inspection. This provides a means for the inspector's recording discrepancies in items, in wrapping or packaging, and in final boxing or crating that may be discovered; besides leaving spaces for Shipping personnel to sign off each discrepancy, when correction has been made, and for Inspection approval of the correction.

In most cases, however, use of this additional form is not necessary, as the Inspection copy of the packing sheet or the request for inspection can be used for this purpose. The reverse side of such forms is usually blank, and the inspector can use this space to note discrepancies or "squawks" that must be corrected before the shipment will be accepted.

SPARE PARTS

All spare-parts orders should receive thorough inspection, not only to make certain that the correct quantities are properly shipped, but also to be positive that the items shipped are those that will actually care for the customer's needs. Probably nothing is more upsetting to a user of the company product than to order urgently needed spare parts for a piece of equipment and then to find, upon their arrival, that the parts will not fit.

While it is undoubtedly true that the prime responsibility for determining the proper spare parts to fill a given need rests with Engineering and the sales department, it should also be a duty of Inspection to perform a last and final check on the correctness of all spares shipments. Inspection should be supplied with a copy of all correspondence and other data relating to the order. When the data indicate that the spares are for a specified serial-numbered end item, Inspection should verify the exact nature of the original parts used to construct the article, working from the inspection log for the end item in question. From this information it should be possible to ascertain the actual change-letter version of the items to be replaced by the spares, and then make certain that each spare is completely interchangeable with the corresponding item used originally in assembling the end item.

The matter of supplying the correct spares in every case is so important to maintaining customer good will that it is desirable to establish definite procedures to be followed when these shipments are being inspected. All spare parts should be checked to relevant drawing prints and specifications, even though this may necessitate unwrapping them for examination.

Deviations should not be accepted unless they are noted on sales order and packing sheet. Minimum considerations to be verified on all spares shipments include

1. Spares must be inspected to the drawing-print revision applicable to the end item for which they are intended.
2. Items normally drilled or reamed to size in fixtures prior to assembly should be in the finish-machine condition.
3. Items normally drilled through at assembly should be undrilled or provided only with pilot holes (depending upon use of jig-drilled

pilot holes in the factory), regardless of whether the drawing print specified full-size holes.
4. Items trimmed to fit at assembly should be untrimmed.
5. Items attached by removable fastenings should be in the finish-painted condition, while those attached by rivets should have only a primer coat.
6. Name plates and lettering should be identical with the legend on the original item.
7. Items should be legibly marked with proper part numbers or be packed in sealed containers identified with the proper numbers.
8. Items should show all required manufacturing Inspection acceptance stamps.
9. Required attaching parts, such as nuts and bolts, should be placed in sealed envelopes or cloth bags and securely attached to the item.
10. Salvaged items may be shipped as spares, provided that the salvage action does not affect interchangeability or the appearance of the item.
11. Spares requiring drilling, trimming, or other fabricating operations by the customer should be accompanied by adequate instructions.

OUTSIDE PRODUCTION

Shipping inspection plays a vital role in the handling of outside production work, wherein raw material and semifinished or finished items are shipped to other firms to accomplish certain fabrication or assembly work under contract. Outside production begins with Shipping and ends with Receiving—just the reverse of the normal manufacturing flow. Items are sent out to other companies for accomplishment of certain work and then returned to the company production flow through the receiving department.

Raw-stock material sent to outside production firms should be checked for quantity, quality, type, heat-treatment, and other requirements established by the drawing print of the item to be fabricated from the material. Rough forgings and castings should also be checked for X-ray, magnetic-particle, fluorescent-penetrant, or other special examinations that may be required.

Semifinished and finished items should be checked for being in the stage of manufacture specified on the packing sheet, in addition to normal examination for lack of damage and proper quantity.

CHAPTER 15

TOOLS AND TOOLING

In addition to routine production-inspection operations, there is normally need for certain precision specialized examinations in support of the production process. These can be grouped into the three broad classifications of *tooling, experimental,* and *laboratory* inspections. In a small organization all three classes may be controlled by a single inspector or inspection group, while a large organization may have a separate subdepartment for each.

Tooling inspection involves the examination and certifying of the correctness of all templates, patterns, tools, gages, jigs, and fixtures required for the production process. This involves not only control of quality during tooling manufacture and acceptance of each tool prior to first production usage, but also continued examination to guard against errors developing through wear or abuse while the tool is used for production, and reexamination of all "used" tooling withdrawn from storage for additional production usage.

Tools can be defined, for the purpose of this discussion, as standard items purchased "over the counter" and normally usable on a variety of company products. Taps, drills, thread gages, and the like are in this category. *Tooling,* on the other hand, comprises special items prepared for use on a certain product or a group of related products, such as templates, patterns, jigs, fixtures, dies, and special tools and gages. Inspection is normally responsible for the quality of both tools and tooling.

TOOL INSPECTION

All tools, including such perishable tools as taps, drills, reamers, countersinks, rivet sets, and milling cutters, affect the quality of the completed end item and should be subject to a positive inspection system. Simply because these items are newly manu-

factured upon their arrival at the company is no guarantee of dimensional correctness. All items of this nature should receive a 100 per cent examination by Tooling Inspection before acceptance.

Reconditioned tools should receive a similar examination prior to their return to tool stores. At periodic intervals, Tooling Inspection should examine all tools maintained in tool stock rooms throughout the plant. Further, if at any time the quality of production indicates that tool deficiencies exist, Inspection should make an examination of any or all suspected tools.

The advisability of maintaining inspection records of *all* tools is highly questionable, although precision tools and gages should be handled in this matter. The cost of maintaining such a system is likely to exceed possible losses from defective tools when a good system of inspection at receiving and following reconditioning and of spot checks during usage is employed.

Some control must also be exercised over personal tools of employees, to insure that these are within acceptable limits of accuracy. Personal tools are usually in the nature of measuring instruments and must be closely controlled when a precision end item is involved.

CONTROL OF COMPANY AND PERSONAL TOOLS

In many large organizations, employees are not permitted to carry or use personal tools within company premises. This simplifies tool control, as then all tools in the factory belong to the company. In the case of smaller companies, this procedure is not economically sound, owing to the large small-tool investment required. Inspectors are then required to use their personal micrometers, depth gages, and precision small tools, subject to company procedures for their recording and control.

When both company and personal tools are in use within the factory, it is desirable to provide a definite procedure for the identification and recording of tools purchased by the company and their subsequent loan to employees. At the same time, it is equally important to provide a record of all personal tools used on company premises by employees.

In practically all cases, small tools are issued to employees from

one or more tool stock rooms (sometimes referred to as "tool cribs"), with a record maintained of each loan. The employee in charge of the tool stock room is the logical person to be assigned the responsibility of maintaining records and control of company and personal tools. Procedures should be established for loan of company tools to employees, records established for listing all personal tools of each employee, together with a system for periodic inspection of the accuracy of all personal precision tools. The personal-tool records should also be used to check the contents of personal toolboxes of each terminated employee, with issuance of a tool clearance being required before payment of termination wages.

While the establishment of a tool-control procedure is actually the concern of all factory departments and must be company-wide to be effective, Inspection personnel normally use a large percentage of precision small tools and may have the largest interest in this subject. On this basis it appears desirable to outline the elements of a practical tool-control procedure.

Company Tools

All company-owned tools should be plainly marked with the company name. It may be desirable to add a serial number to the company identification on certain tools, to provide positive identity for each tool loan. The company name can be applied with either a steel stamp or an electric pencil, depending upon the nature of the tool.

In many cases it is possible to avoid the nuisance of stamping each new tool immediately upon its receipt by specifying on purchase orders that the tools are to be marked with a certain legend by the vendor. An accurate inventory record (see Fig. 15:1) should be maintained of all company tools, specifying not only kind and quantity, but also the serial number of each and the frequency of its usage, as a guide in adjusting inventory minimum and maximum values.

Loaning Company Tools

There are two basic systems used for recording the loan of company tools to employees. One method involves issuing a cer-

tain number of serialized tool checks to each employee at the time of his employment. When the employee obtains a tool from the stock room, a tool check is left with the storekeeper, to be filed in place of the loaned tool. Upon the tool's being returned to the toolroom, the corresponding check is surrendered to the employee. At the close of business each day, the unclaimed tool checks are

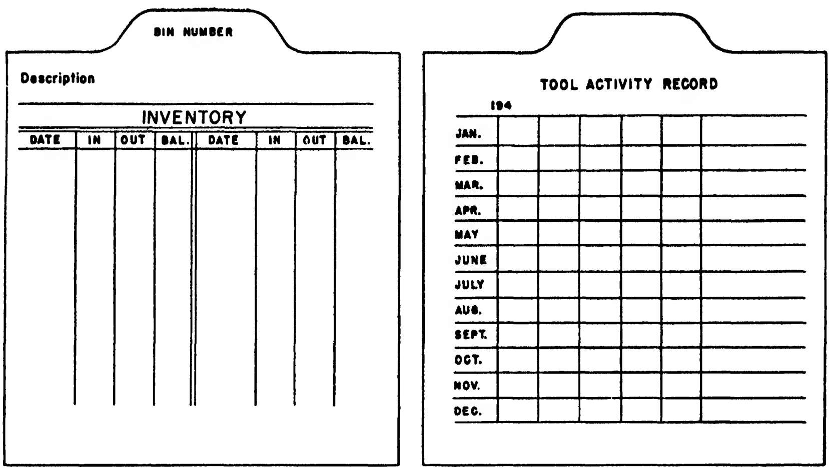


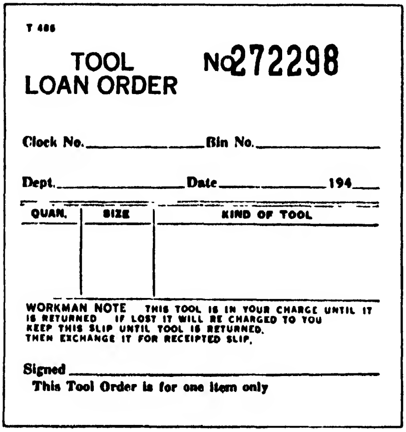
FIG. 15:1. Perpetual inventory record for tools. Back of form provides for recording number of loans each month, as a tool activity record. (*Courtesy of McCaskey Register Company.*)

recorded, and the foremen of the erring employees are notified to have each employee return the missing tool, subject to a penalty of being charged for each tool not returned. A nominal value is placed upon tool checks, and the employee is charged for each lost check. In the event of lost tools or checks being recovered, the employee is credited with their value.

The other system does not use tool checks, but requires each employee borrowing a tool to sign a receipt in triplicate for each tool obtained on loan. The original and the duplicate are retained by the tool storeskeeper for filing under the employee's clock number and in front of the inventory card for the type of tool loaned. The triplicate copy is given the employee for his record.

Upon the tool's being returned, the original receipt is sur-

rendered to the employee and the duplicate is moved to *behind* the inventory card, to indicate that the tool has been returned. Once a month, the quantity of slips accumulated behind each card is counted and posted to the tool's activity record. At the close of each shift, the unreturned tools are checked from the unclaimed receipts, and the foremen of erring employees are notified.



T 486

TOOL LOAN ORDER No 272298

Clock No. ______ Bin No. ______

Dept. ______ Date ______ 194__

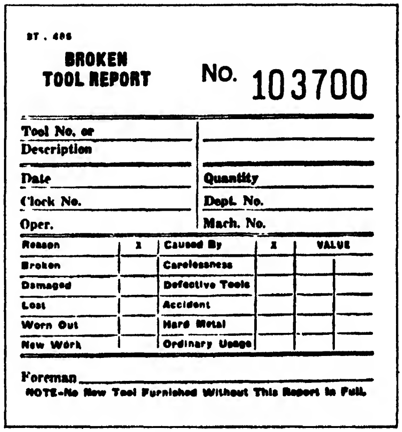
QUAN.	SIZE	KIND OF TOOL

WORKMAN NOTE THIS TOOL IS IN YOUR CHARGE UNTIL IT IS RETURNED IF LOST IT WILL BE CHARGED TO YOU KEEP THIS SLIP UNTIL TOOL IS RETURNED. THEN EXCHANGE IT FOR RECEIPTED SLIP.

Signed ______

This Tool Order is for one item only

FIG. 15:2. Tool charge-out receipt. (*Courtesy of McCaskey Register Co.*)



ST. 486

BROKEN TOOL REPORT NO. 103700

Tool No. or Description ______

Date ______ Quantity ______

Clock No. ______ Dept. No. ______

Oper. ______ Mach. No. ______

Reason	X	Caused By	X	VALUE
Broken		Carelessness		
Damaged		Defective Tools		
Lost		Accident		
Worn Out		Hard Metal		
New Work		Ordinary Usage		

Foreman ______

NOTE—No New Tool Furnished Without This Report In Full.

FIG. 15:3. Broken or worn tool report. (*Courtesy of McCaskey Register Co.*)

Lost tools are charged to the employee in the usual manner, and toolroom clearance is required before payment of termination wages.

All returned tools are examined for breakage before the original copy of the tool receipt is surrendered. A broken or damaged tool is not accepted, unless accompanied by a *broken-tool report* (see Fig. 15:3) countersigned by the employee's foreman.

The latter system has the advantage of eliminating the nuisance of tool checks and provides positive, indisputable evidence of loans. The employee's signature on the receipt ends all possibility of argument over responsibility for lost tools.

Complete packaged systems of forms, filing boards, and the like for the receipt system of tool control are available through industrial service organizations and are worthy of investigation whenever a tool-control system is planned.

Personal Tools

The basis of personal-tool control involves elimination of employee-owned tools identical with those normally loaned by the tool storeroom, and the establishing and maintaining of a record of the remainder of the employee's tools. All new factory employees should be escorted to the tool storeroom for inventory of their toolboxes before reporting to their supervisor for work assignment. The person in charge of the toolroom should make an inventory of all tools belonging to the employee and should separate these into two groups. The first group will comprise those tools normally issued by the tool storeroom—hacksaw blades, drills, taps, dies, files, reamers, electric drills, and the like. Personal tools of this nature should not be permitted in the factory. After segregation, these should be placed in a paper or cloth bag, sealed, and returned to the employee, to be taken out of the factory at the close of his shift.

The second group of employee tools will comprise items not normally loaned by the tool stockroom. These should be recorded on an *employee personal-tool record* and returned to the employee, to be kept within the factory during the term of his employment. Personal tools kept within the factory should be identified with the employee's name when the nature of the tool permits marking with an electric pencil.

Whenever the employee obtains additional tools, either through outside purchase or from another employee, these should be taken to the tool stock room for recording. If the acquisition is through purchase from another employee, both should go to the stock room to have their personal-tool records changed accordingly.

Toolbox Inspection

Many companies require a period inspection of all toolboxes, to make certain that all employees have complied with personal-tool regulations. These inspections should be held at intervals not exceeding 3 months. All tools belonging to the company discovered during toolbox inspections should be immediately returned to the tool stock room, and the employee's foreman should be notified of the findings.

Termination of Employment

Upon an employee's terminating employment with the company, his toolbox should be presented to the attendant in charge of the tool stock room for checking and issuance of a tool clearance. All tools not recorded on the employee's personal-tool record should be removed from the toolbox and impounded. The remaining tools should be replaced and the toolbox securely sealed and forwarded to the personnel department. The box is then given to the employee, together with his termination check.

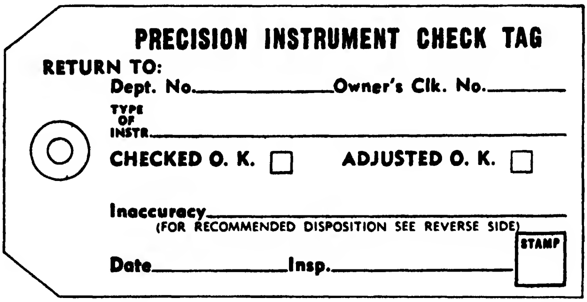
When a plant-protection system is in effect, with guards at all company entrances, the employee can be given a toolbox pass and permitted to remove the sealed toolbox from company premises immediately after inspection by the stock-room attendant.

Impounded tools not listed on the employee's tool record should be held in the tool stock room pending establishment of ownership. The responsibility for proving ownership should rest on the employee, rather than on the company. This is reasonable and proper when all employees receive formal notification of regulations relating to tool control upon beginning their employment.

PRECISION-TOOL AND GAGE INSPECTION

Gage control is an important function of the inspection department. This activity relates not only to gages, but also all other precision tools and measuring instruments (both company and employee owned), although a majority of its work involves production gages used to maintain interchangeability. Control of gages and precision tools involves the following steps: (1) inspection of all gages and precision tools immediately upon receipt at the company, including all personal items of employees; (2) recording each item in a manner describing and identifying its original condition and providing indication for periodic reexamination periods; and (3) regular, scheduled reinspection of all items, to insure that wear or damage has not rendered them inaccurate.

All precision tools and gages that, through their shop usage, might affect product quality or interchangeability should be routed to the gage-control section of Inspection immediately upon being received at the company. The final decision on acceptance or rejection should be made by Gage Control. All accepted items



PRECISION INSTRUMENT CHECK TAG

RETURN TO:

Dept. No.________ Owner's Clk. No.________

TYPE OF INSTR.________

CHECKED O. K. ☐ ADJUSTED O. K. ☐

Inaccuracy________
(FOR RECOMMENDED DISPOSITION SEE REVERSE SIDE)

Date________ Insp.________ STAMP

FIG. 15:4. Precision instrument check tag issued to employee to authorize use of personal gage or instrument.

should be identified by serial numbers, and records (see Fig. 15:6) should be established for each. Personal tools of employees should be treated in a similar manner, and a precision-instrument check tag (see Fig. 15:4) should be issued and attached to each. This tag should be retained by the employee as an evidence of authority to use the item.

GAGE-CONTROL PROCEDURE

The gage-control procedure instituted by Air Associates, Inc., manufacturers of precision electrical, mechanical, and hydraulic components, illustrates the elements of a procedure adaptable to any product manufactured to precision tolerances.[1]

Control of gage size is obtained by two basic procedures: (1) periodic inspection, whose frequency is governed by the tolerance of the part on which the item is employed and the amount of usage; (2) routine inspection by the gage-control department before the reissue of *all* gages returned to the tool crib, regardless of how brief the period of use may have been. Since most gages are returned at shift end, in actual

[1] Cortlyn W. Rhodes, "Better Quality through Positive Gage Control," *Factory Management and Maintenance*, July, 1944, p. 99.

practice routine inspection of active gages supersedes periodic inspection.

The chart . . . [in Fig. 15:5] . . . shows the flow of gages through the system and the relation of various forms and records [see Fig. 15:6] needed so that the gage-control department may know the location and condition of each item.

Upon receipt in the gage-control department, all new gages are processed in the following manner:

1. Gage is inspected. Gage ticket [Form 1, Fig. 15:6] showing actual measurement compared with (allowable) maximum and minimum sizes is affixed by inspector, who dates and initials ticket. Basic information on ticket has previously been filled in by clerk.

2. Information from *gage ticket* plus purchasing information is transcribed on *gage and tool record* [Form 2, Fig. 15:6] by clerk who assigns serial number. This step initiates a historical record that is terminated only by ultimate rejection of gage.

3. Serial number is etched on gage where most convenient.

4. Record of new gage is made on *gage reference* [Form 3, Fig. 15:6] for particular size; inventory record is adjusted.

5. Gage is released to tool crib with gage ticket still affixed. This ticket certifies to attendant that gage is O.K. for use. All gages held in crib for issue bear this ticket, and attendant is not authorized to issue any gage not so certified.

6. Gage is issued to operator who executes *tool loan order* [Form 4, Fig. 15:6] in triplicate for each item. Attendant marks ticket plainly with serial number of gage issued. Operator receives gage minus *gage ticket*, which attendant sends back to gage-control department along with tissue copy of *tool loan order*. Attendant subsequently files the original of *tool loan order* under operator's number in special file and the yellow copy in a similar file according to gage size. These files furnish a complete cross reference on the employee and the item.

7. Upon receipt of *gage ticket* and tissue copy of *tool loan order* in the gage-control department, clerk posts date of issue and operator's number on *gage and tool record* and installs "flag" for periodic inspection, which indicates gage is now active.

8. If gage is not returned before reinspection date as "flagged," tool crib is notified by execution of a *gage and tool receipt* [Form 5, Fig. 15:6] presented by messenger, and gage is recalled for check. If gage is returned to crib prior to periodic inspection (as it is in most cases), it is returned to gage control with yellow copy of *tool loan order*. Original copy of *tool loan order* (white) is removed from operator's file.

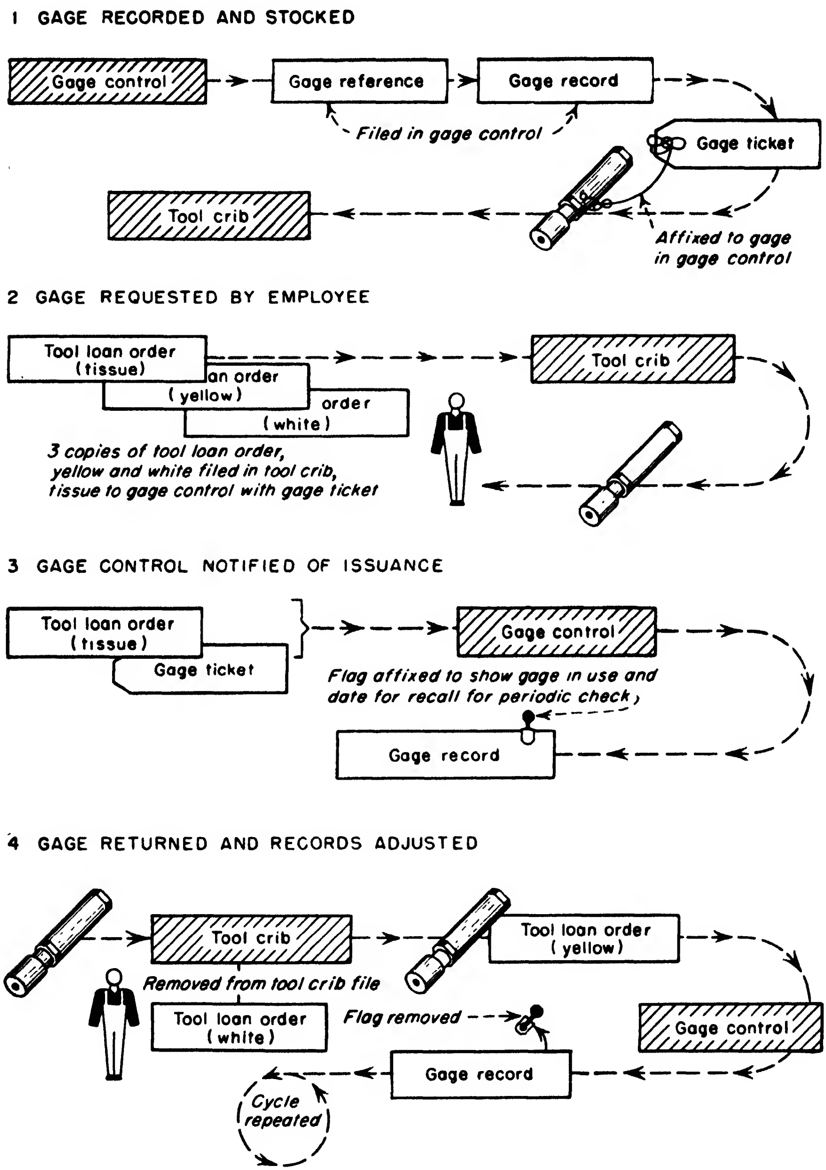


FIG. 15:5. Flow chart of gage-control plan.

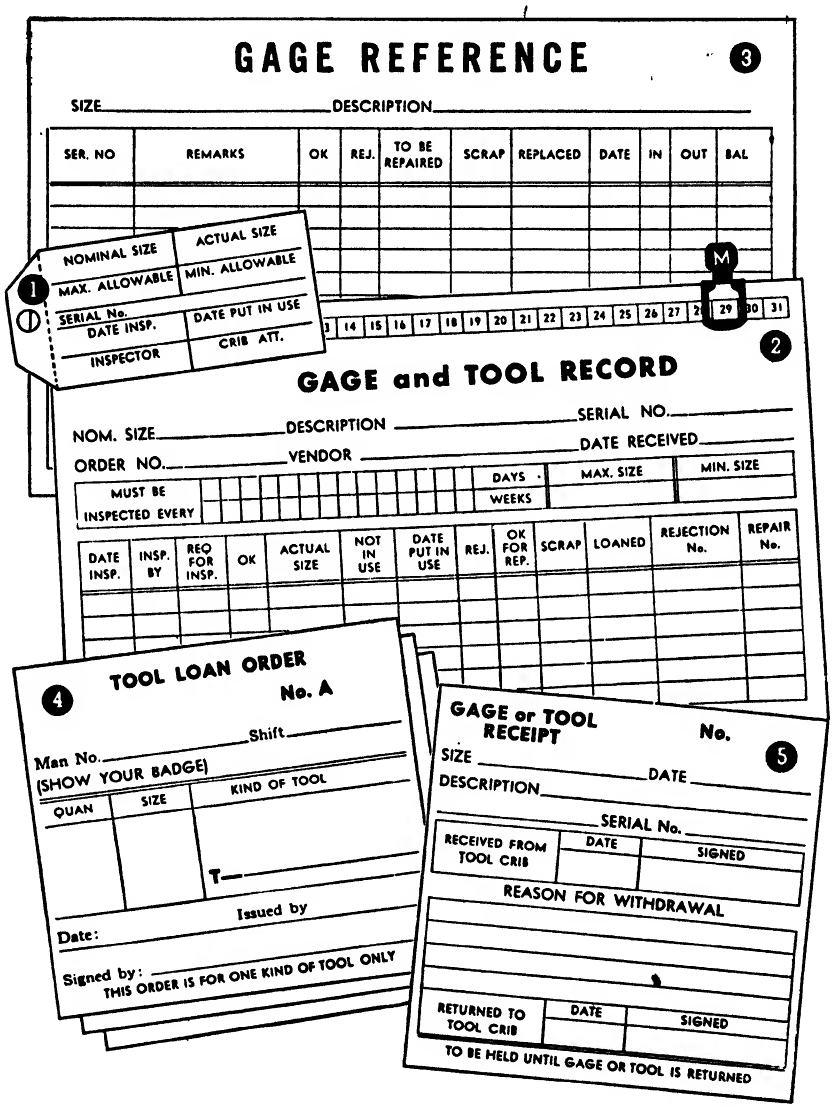


FIG. 15:6. Names of forms at Fig. 15:5 correspond with names on actual paper work. Gage ticket (1) is key to control plan and stays with gage until issued to user.

9. New gage ticket is prepared by clerk, and gage is reinspected. If gage shows undue wear or abuse, yellow ticket permits investigation of cause.

10. Record of inspection is entered upon *gage and tool record.*

11. Gage is released to tool crib and cycle is repeated.

12. Gage is ultimately rejected. Rejection tag is affixed and proper parties are notified through tool rejection report form.

13. Record of rejection made on gage reference and inventory figure is adjusted.

14. Gage-control department adjusts inventory records to agree with rejection and reorders if necessary.

Gages on loan to subcontractors are controlled through the same central system.

GAGE CLASSES

When the product is of considerable precision, there is need to extend further the basic gage-control procedure, to provide for definite *classes* of gages. Unless this is done, there may be continual bickering between Production and Inspection over parts that are correct according to the gage used by Production, but outside limits according to the Inspection gage.

A majority of gaging involves control of dimensional limits of mating cylindrical parts, and plain and threaded plug and ring gages are used. Three classes of gages should be maintained: production, inspection, and basic.

Production gages produce parts to limits slightly less than the drawing limits. The corresponding inspection gage will accept a part within the full dimensional limits, insuring that parts produced to the production gage will be accepted at inspection. Basic gages check the nominal dimension and are used to verify dubious cases.

Use of the three classes can be illustrated by the gages suitable for a tapped hole. The production threaded plug go gage should be new, containing the maximum wear allowance and consequently slightly larger than the thread basic-pitch diameter. The inspection go gage should be very close to the pitch diameter and is probably a worn gage retired from production checking, but still within limits. The basic gage is exactly on the basic-pitch diameter. Thus a tapped hole that receives the production go

gage will be slightly larger than the basic-pitch diameter, insuring that the inspection go gage will fully engage and that the basic gage can be inserted with ease. Unless this relationship is maintained, friction will arise between Inspection and Production from rejection of parts that fit production gages but fail to accept corresponding inspection gages.

FREQUENCY OF PRECISION-TOOL AND GAGE INSPECTION

The frequency of inspection periods for precision tools and gages will vary somewhat with the degree of quality to be maintained and the nature of usage. The following schedule has been found satisfactory in cases where a reasonable degree of precision must be maintained.

Micrometers. Every fifth working day
Snap, plug, and ring gages (plain). Every fifth working day
Snap, plug, ring, and roll gages (thread). At end of each shift
Dial gages. Monthly
Height gages. Every tenth working day
Levels and transits. Every fifth working day
Torque wrenches. Every fifth working day
Straightedges. Monthly

Rejected company precision tools and gages that cannot be repaired or adjusted with the facilities available in the gage-control group should be forwarded to the Inspection salvage accumulation area for salvage action. Rejected employee-owned tools should be returned to the employee and the employee's supervisor notified in writing that the item has been rejected. It then becomes the supervisor's responsibility to see that the rejected item is not used and is removed from the factory by the employee.

Tools and gages forwarded to the gage-control group by Receiving Inspection should be examined, the *receiving report* marked with the disposition, and both items and report returned to Receiving. Receiving will then make proper disposition in accordance with the information shown by Gage Control on the receiving report.

PROJECT TOOLING

Tooling designed for use on a specific end item can be designated as "project tooling," to distinguish it from so-called "standard" tools, usable on a wide range of end items and usually purchased as "over-the-counter" items. Machining fixtures, assembly jigs, and special Inspection checking fixtures are examples of

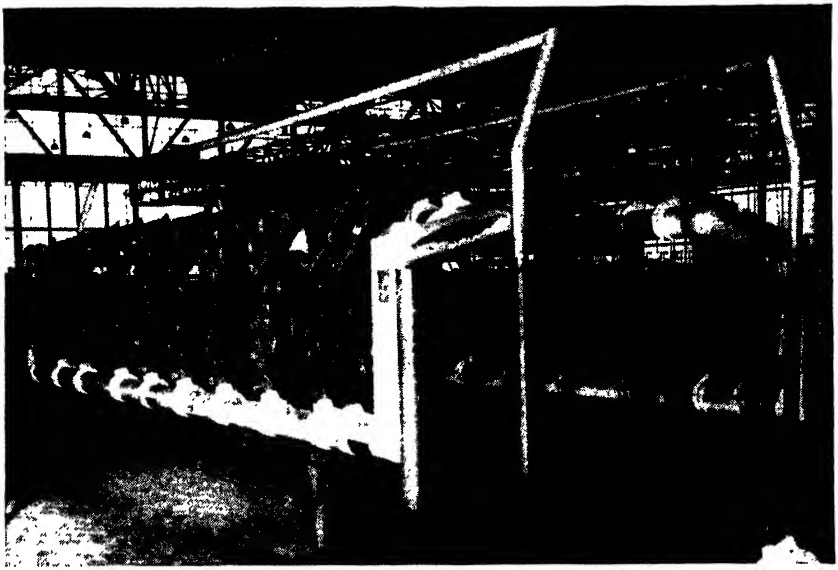


FIG. 15:7. Assembly jig employed to insure dimensional accuracy of motor coach body upper subassembly illustrated at Fig. 12:8. Use of accurate tooling eliminates necessity of fitting at assembly, and reduces manufacturing expense. (*Courtesy of The Nashville Corporation.*)

project tools, as are drills, reamers, and milling cutters reground to nonstandard dimensions to machine certain parts.

A majority of project tooling will comprise templates, patterns, dies, fixtures, jigs, and special gages. Templates can be grouped into two broad classifications—*flat-pattern* and *form.* Flat-pattern templates describe the correct outline of the sheet-metal blank that will produce the required part after forming or drawing to shape. Form templates are used to check contours or angles of parts during or following fabrication operations. Patterns are used to prepare molds for casting.

Dies are used to blank, bend, form, or draw parts to required dimensions and shape. Fixtures are employed to hold a part while it is being machined to definite dimensions, such as a milling fixture, designed to hold and locate a part while it is being milled to a specified dimension in a given location.

Jigs are intended to locate a group of parts comprising an assembly, to insure that all assemblies will be dimensionally interchangeable; or they may be drill jigs, designed to locate a part to certain reference points while it is being drilled and/or reamed.

Special gages are often used when considerable production is planned for a certain part, to permit checking dimensions without necessity of actual measurement of each part. These are usually in the form of go and not-go plug, ring, or snap gages, designed to check a specific nonstandard dimension.

Tooling Inspection has the responsibility of ascertaining that all project tooling is properly designed to accomplish the desired objective and sufficiently sturdy and rigid to withstand reasonable handling without loss of dimensional accuracy. There is also a continuing responsibility for periodic reexamination of all project tooling, to make certain that it is still within the required limits of accuracy.

Project tooling is normally made by the tool-manufacturing department, although in some cases certain tooling may be purchased—dies and patterns, for example. Revision and repair of existing tooling are also accomplished by Tool Manufacturing, normally in accordance with Inspection instructions, and the corrected tooling is reinspected prior to production usage.

Periodic reinspection of jigs and fixtures is normally conducted throughout their production usage. The frequency of these examinations must be determined by experience—some tools requiring weekly inspection, while others may safely be inspected but once each month. Records should be established for each jig and fixture, showing its length of service and all troubles experienced. These can be used as a guide in establishing inspection periods and procedures. Specific wear allowances should be established for each jig and fixture. When these limits are reached, the tool should be rejected and returned to Tool Manu-

facturing for repair. This is followed by reinspection and reacceptance for production usage, if the tool is found satisfactory after repair.

TOOLING INSPECTION

The detail procedure suitable for inspecting and proofing production tooling will vary somewhat with the nature of the end item and the degree of quality and interchangeability to be maintained. In general, all tools and tooling that control and/or affect dimensional and quality characteristics of the end item should receive Inspection approval prior to production usage.

Tooling Inspection is responsible for the examination of all

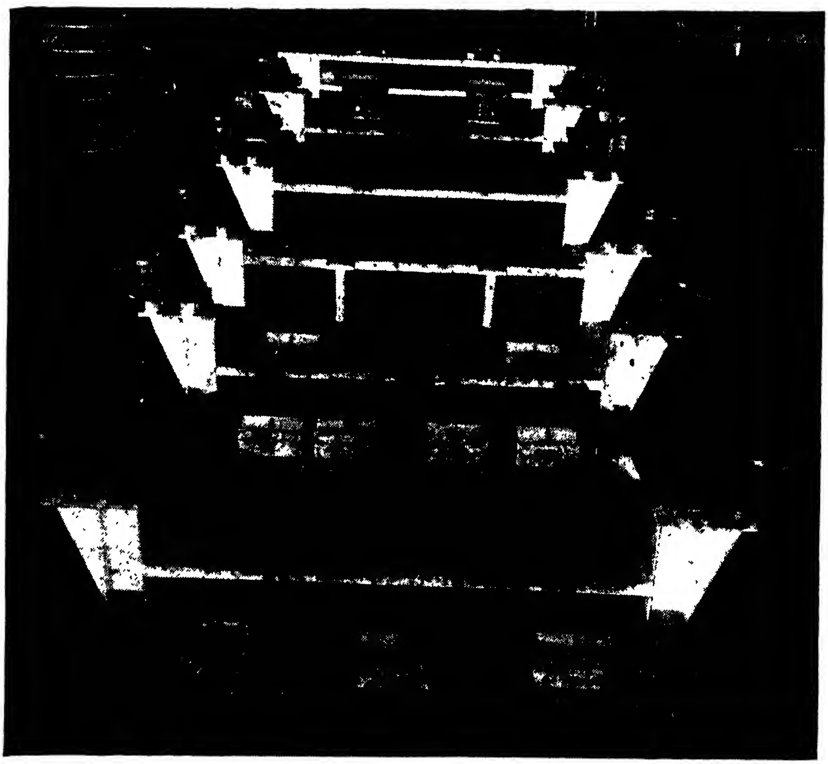


FIG. 15:8. Assembly jig for motor-coach underframe. Tooling of this nature reduces the expense of producing the item, and insures that each item will join its next assemblies without need for hand fitting. (*Courtesy of The Nashville Corporation.*)

company-manufactured or purchased production tooling and for acceptance or rejection of it, based upon ability to produce acceptable and, when required, interchangeable parts under normal operating conditions. The following general procedure can be followed to insure adequate inspection and proofing of production tooling.

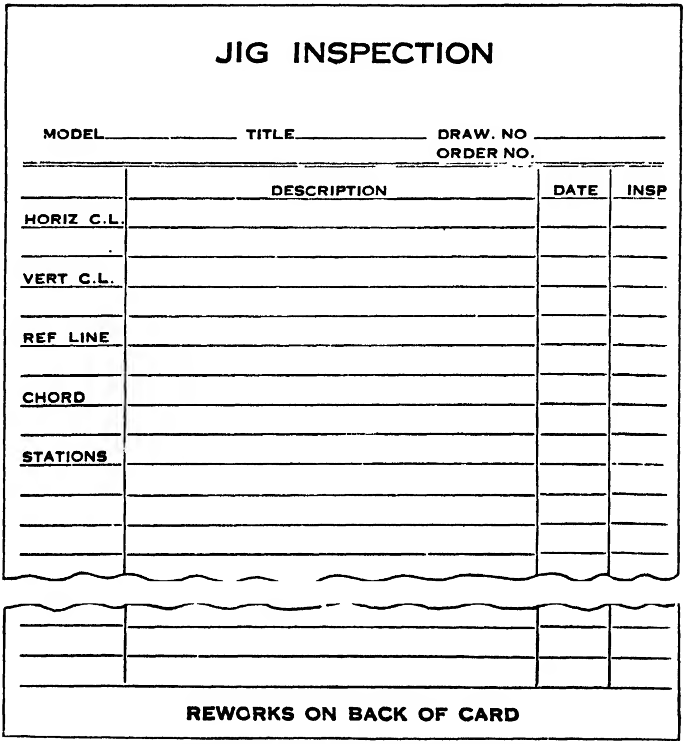
The tool-manufacturing department should notify Tooling Inspection when tools have been completed or are ready for a progressive inspection operation. All data used in manufacturing the tool (such as engineering drawing prints, tool-design sketches, tool orders, tool layouts, and coordinating tooling) should be delivered to Inspection at this time. Tool manufacturing should coordinate with Inspection in the case of large or complicated tools, to determine whether progressive inspection is required during construction of the tool. When progressive inspection is required, Inspection should notify Tool Manufacturing of the steps at which examinations will be necessary, and should establish a record similar to that shown in Fig. 15:9, to record inspection progress.

Prior to presenting the tool for final acceptance inspection, Tool Manufacturing should stamp, adjacent to the tool number appearing on a plate or pad, the following notations: "TOOL INSP" and "PROOF INSP." The tool inspector's acceptance stamp will be placed after one or both of these notations upon final acceptance of the tool. When it is deemed necessary by Inspection, the tool-manufacturing department should also make trial parts to proof the tool and should submit the proof parts with tool and reference data to Inspection.

Tooling Inspection should check the tool against the tool manufacturing order, all reference data used in manufacturing the tool, and the latest engineering drawing print or prints of the items to be produced with the tool. If the tool is found to be acceptable, Tooling Inspection should mark the tool with an acceptance stamping, adjacent to the "TOOL INSP" notation and should apply an acceptance stamp to the tool-manufacturing order.

When a proof of the first-run part is checked for conformance to latest released engineering information and is found to be

acceptable, the tool inspector should also place an acceptance stamp adjacent to the "PROOF INSP" notation. If proof inspection is not applicable, the tool inspector should stamp "NA," followed by an acceptance stamp, adjacent to the proof notation on the tool identification plate or pad.



JIG INSPECTION

MODEL______ TITLE______ DRAW. NO ______
ORDER NO.______

	DESCRIPTION	DATE	INSP
HORIZ C.L.			
VERT C.L.			
REF LINE			
CHORD			
STATIONS			

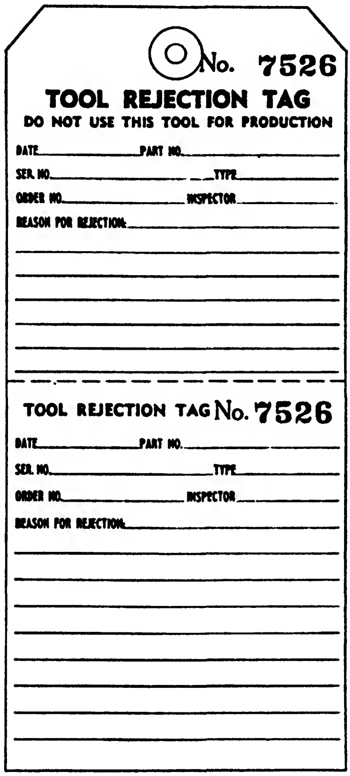
REWORKS ON BACK OF CARD

FIG. 15:9. Record for itemizing progressive inspection steps accomplished during construction of a complicated jig.

TOOL-REJECTION NOTICE

If the tool is found to be unacceptable, the tool inspector should originate a *tool-rejection notice,* listing the discrepancies, should attach the notice to the tool and return the tool to Tool Manufacturing for corrective action. A notation of the rejection should appear on the inspection flow record maintained by Tool Inspection, in order that Production Control may be notified of the rejection.

The tool-rejection notice form shown in Fig. 15:10 comprises two identical halves—one for attachment to the rejected tool and the other for forwarding to Tool Manufacturing's office. Each half of the notice contains the following information:



No. 7526

TOOL REJECTION TAG

DO NOT USE THIS TOOL FOR PRODUCTION

DATE ______ PART NO. ______

SER. NO. ______ TYPE ______

ORDER NO. ______ INSPECTOR ______

REASON FOR REJECTION: ______

TOOL REJECTION TAG No. 7526

DATE ______ PART NO. ______

SER. NO. ______ TYPE ______

ORDER NO. ______ INSPECTOR ______

REASON FOR REJECTION: ______

FIG. 15:10. Tool rejection notice, made in two identical parts, one to be attached to the rejected tool, the other forwarded to Tool Manufacturing.

Date. Date the rejection notice is issued
Part No. Part number of item to be produced with tool
Ser. No. Tool identifying number and/or serial number of tool
Type. Kind or type of tool
Order No. Serial number of tool manufacturing order
Inspector. Inspector's initials and stamp
Reason for Rejecting. Description of the deficiency or deficiencies causing rejection of tool. Tool Manufacturing will be guided in taking corrective action by the information given here and can be expected to correct only the listed discrepancies and none other.

When proof inspection was not accomplished prior to releasing the tool for production usage, and the nonapplicable (NA) symbol does not appear following the proof inspection notation, it should be necessary for factory supervision to submit to Production Inspection the first part produced by the tool and to obtain acceptance before continuing usage of the tool. Upon the first part's being found acceptable by Production Inspection, an Inspection acceptance stamp should be placed adjacent to the "PROOF INSP" notation, and the tool should be released for continued production.

From time to time, tools will be withdrawn from production and sent to Tool Manufacturing for rework, in accordance with engineering drawing changes. These reworked tools must be reinspected and reaccepted prior to their return to production usage. All accepted reworked tools should be stamped with the drawing revision letter, or number to which they have been reworked, and this followed by a Tool Inspection acceptance stamp. These markings should appear on the identification plate or pad used for the original Inspection acceptance markings.

PERIODIC REINSPECTION OF TOOLING

Tool Inspection should establish an index of all production tools requiring periodic examination and should reinspect each at the required intervals, to insure continued serviceability. Additional, nonscheduled inspection may also be required if it is requested by a production inspector or by factory supervision. If repair or correction is found necessary, a tool-rejection notice should be issued and the tool be sent to Tool Manufacturing or, in the case of a large tool, the lower portion (see Fig. 15:10) of the rejection notice only should be sent to Tool Manufacturing. The tool cannot be used for production until the rejection is corrected and the tag is removed from the tool by the accepting tool inspector. This portion of the tag is stamped "Accepted" by the inspector and is forwarded to the Inspection office for clearing the tooling-rejection follow-up file.

Production inspectors should, as part of their normal duties, examine tooling for evidence of undue wear or improper usage. Tooling Inspection should immediately be notified of all apparent

discrepancies, and factory supervision should be informed of all instances of improper usage of tooling.

HANDLING-EQUIPMENT INSPECTION

Handling equipment used in production operations is as important as tooling. Not only is it possible for items to be damaged or distorted by deficient handling equipment, but in many cases serious safety hazards may be created.

All production inspectors should be alert for evidence of improper handling equipment and should immediately bring to the attention of Tooling Inspection any apparent defects. Handling equipment found to be defective should be rejected through the medium of a tool-rejection notice, and the rejected item be forwarded to the proper department (usually Maintenance) for corrective action. The location of the defective item should be clearly noted on the notice, so that it may be returned to its original location without difficulty. Should the nature of the item be such that movement to another area for repair is impractical, the lower portion of the notice should be forwarded to the department responsible for correction. The rejection notice attached to the item must remain in place until corrective action has been completed to the satisfaction of Inspection, and the item should not be used until the rejection tag is removed by Inspection.

Handling equipment, such as slings and workstands, wherein failure might endanger personnel or property should be recorded and inspected in accordance with established procedures and fixed schedules. Tooling Inspection should maintain a record of such equipment and post to the record the date of each inspection, the condition found, and the action taken. In some cases the inspection of handling equipment is assigned to Maintenance, and Tool Inspection is not involved.

CHAPTER 16
EXPERIMENTAL AND LABORATORY

Experimental and laboratory inspection operations form a logical grouping, for the nature of experimental activities normally places considerably more demand upon the laboratory facilities than does production. During the progress of experimental work there is need for Inspection to work closely with Engineering to develop basic test procedures that will later be applied to production items, and this requires the know-how of both the experimental inspectors and the inspection laboratory.

In a small plant where an Inspection laboratory is not maintained, it will be logical to combine experimental and tooling inspection activities; but whenever a laboratory exists, this should be consolidated with experimental inspection work. Large operations will, of course, find it desirable to establish separate experimental and laboratory groups within the inspection department.

FUNCTIONS OF EXPERIMENTAL AND LABORATORY INSPECTION

Experimental inspection involves all basic operations found in production quality control, but to a more exacting degree, and often in the absence of complete reference information. Inspection personnel engaged in this work must have the highest degree of competence and be able to judge the correctness of a part or assembly without complete detail drawings, specifications, or work instructions, being guided to a great extent by knowledge of shop practice, precision measuring methods, test procedures, and service requirements.

Laboratory inspection verifies performance, physical and chemical properties of purchased precision components and raw-stock materials, as well as such production processes as heat-treatment and electroplating. Various purchased components, such as in-

struments, control valves, and electrical apparatus, cannot be adequately checked for proper performance by Receiving Inspection and must be routed to the Inspection laboratory for performance testing.

Raw-stock materials often must be tested for conformance to specified physical properties and chemical compositions. These examinations also are beyond the normal scope of Receiving Inspection, and either samples must be sent to a commercial laboratory or an Inspection laboratory must be established. The same holds true of manufacturing processes that have as their purpose alteration of physical properties or application of protective and/or decorative coatings. To obtain consistent and satisfactory results from these processes, it is necessary to make periodic physical and chemical tests of specimens and of the various compounds and solutions employed. The choice of having the actual testing accomplished by a commercial laboratory or by Inspection should be based upon purely economic considerations. An Inspection laboratory should be established only when physical and chemical testing work reaches a level sufficient to justify the expense of establishing and maintaining a company laboratory.

Another important function of the Inspection laboratory is to establish test and process specifications for the guidance of Production Inspection. These are normally established in collaboration with Engineering and detail the procedure to be followed for various performance tests. Process specifications establish operating conditions that must be maintained during processing treatment or application, and they provide production inspectors with criteria for accepting or rejecting process work.

EXPERIMENTAL INSPECTION

The basic functions of experimental inspection involve the following responsibilities:

1. Examining items received in the experimental department
2. Examining tools and tooling used for experimental manufacture
3. Examining items produced in the experimental department
4. Inspecting and controlling processes applied to experimental items
5. Examining mock-up assemblies and installations made in Experimental

6. Inspecting and testing completed experimental end items
7. Disposing of all items listed in (1) through (6) by
   a. Accepting them as meeting requirements, with appropriate stamping of items and paper work
   b. Returning them for rework as deficient items practicable of correction
   c. Rejecting those which do not meet requirements and which appear impracticable of rework, with suitable stamping of the item and issuance of rejection notice
8. Maintaining *inspection flow record* of items examined on each shift
9. Maintaining a complete history, in the form of an *inspection log*, for each experimental end item
10. Developing preliminary test specifications for the end item, for subsequent production usage
11. Maintaining liaison with Engineering, to eliminate difficult fabrication and assembly operations that may render production of the end item impractical or unnecessarily costly

From the foregoing it can be seen that the basic operation of experimental inspection is almost identical with that maintained in production departments, varying principally in the degree of individual initiative and experience required. Identical inspection forms and records should be maintained in both cases. A complete cycle of receiving, fabrication, assembly, test and final acceptance, tooling, and process examinations should be maintained by Experimental Inspection.

Recording Experimental Changes

The prime purpose of the experimental effort is completion of a successful prototype that can be rapidly transformed into a production end item. The transition to production becomes difficult, if not impossible, in the absence of a complete, accurate record of all changes found necessary during construction of the experimental end item.

Compilation of this record requires registry of every change found necessary during experimental work, and this logically becomes a responsibility of Inspection, which must accept each and every part of the experimental end item. The information provided should be sufficiently complete to permit a qualified engineer, without prior knowledge of the end item, to prepare readily

final corrected data describing the exact nature of the completed prototype. In the case of a small organization, where experimental inspection is accomplished by a single person or a very small group, it is practical to solve the problem by releasing a set of "inspection master prints" to the person in charge of experimental inspection. All changes found necessary during construction and testing are marked on these prints. These data can be used later by Engineering to correct the drawings describing the end item. Additional changes considered desirable as production improvements can be noted on the marked-up prints or requested through the medium of drawing-change requests.

A large organization involving considerable personnel in the design, construction, and inspection of an experimental end item requires different methods of maintaining change history and requesting production-improvement changes. It becomes difficult to insure that all changes are marked on the master prints, and the hazard of their loss increases in proportion to the personnel handling the prints. Therefore, it becomes necessary to establish an *inspection log* for each experimental end item and to use records, in the form of drawing changes, advance drawing changes, engineering orders, and drawing-change requests, describing each alteration made or considered desirable in the end item. These can later be incorporated into their respective drawings, to obtain final corrected production data.

INSPECTION LABORATORY

The basic functions of an Inspection laboratory involve the following responsibilities:

1. Testing materials requiring chemical or physical testing
2. Testing of components requiring functional testing
3. Special chemical, physical, and functional tests for production inspection, as approved by the chief inspector
4. Checking and verifying completeness of test reports received from vendors
5. Examination of processing equipment and instrumentation, and analysis of compounds and solutions
6. Examination of equipment and workmanship involved with specialized operations, such as spot and fusion welding

7. Specialized technical examinations, such as X-ray and fluorescent-penetrant tests, when the magnitude of this work does not justify its being established in a separate group
8. Inspection of hardness-testing equipment
9. Preparation of test specifications
10. Development of production test equipment
11. Examination of production test equipment
12. Control of testing work forwarded to outside laboratories
13. Record of equipment requiring periodic examination, results of tests, and corrective action applied to defects
14. Records of chemical, physical, and functional tests of materials, components, and company-manufactured items; and distribution of copies of test reports to all interested parties

From the foregoing it can be seen that the prime duties of the Inspection laboratory involve accomplishment of chemical, physical, and functional testing required for basic inspection operations, and maintenance of adequate test specifications. Secondary duties involve periodic examination of precision-testing equipment, design of production-testing equipment, and accomplishment of special tests required by Production Inspection. In addition, the Inspection laboratory may be required to accomplish repairs on precision components and instruments rejected by Production Inspection, on the basis that facilities for their repair and calibration exist in the laboratory and that establishment of the necessary facilities elsewhere would be duplication and unnecessary expense.

PROCESS-CONTROL INSPECTION

The process-control inspection required for precision end items may become quite involved and exacting. For instance, control of heat-treatment of aluminum-alloy rivets requires that the Inspection laboratory check all rivet heat-treating furnaces once each hour, to make certain that the proper alloy is being heat-treated at the correct temperature for the proper length of time. When recording temperature indicators are used, the inspector should stamp the graph sheet, to indicate that correctness of alloy being heat-treated, cleanliness of containers, and heat-treatment temperature have been verified. The graph sheets are re-

moved at the end of each time period and are forwarded to the Inspection laboratory office. When indicating temperature gages only are used, the inspector should prepare a written report of hourly examinations and forward this to the Inspection laboratory office.

At least once each week, the accuracy of temperature recorders or indicators should be verified, and the results be forwarded to the inspection laboratory office. In the event of unsatisfactory operation found during this or any other inspection, the laboratory inspector should report the facts to the foreman in charge of heat-treatment, the maintenance department, and the laboratory inspection office. Use of the furnace should be discontinued until Maintenance has completed necessary repairs and Inspection has verified proper operation.

TEST SPECIFICATIONS

An important function of the Inspection laboratory is preparation of test specifications to establish procedures used within the laboratory, by Receiving Inspection and by Production Inspection groups engaged in functional testing of completed end items or their components. These will vary greatly in nature, but should always specify the test equipment required, test conditions, and test procedure, similar to the following example.[1]

Functional Test Procedure
for
Propeller Feathering Pump
(Brands and models of pumps covered by Procedure)

Test Equipment:

1. Engine oil test stand
2. 24-volt dc power source

Test Conditions and Requirements:

1. All testing at 24-volts dc
2. Using AN–VV–O–446a, Grade 1120 oil at 155°F±5°, pump shall have a minimum flow of 3.75 gpm. at 1,000 psi. and not over 175 amperes current consumption

[1] Based upon Lockheed Aircraft Corporation, Burbank, Calif., *Functional Test Procedure* G–3032, dated June 16, 1943.

3. Relief valve to be set at 1350±50 psi.
4. Recirculation system to be checked, using AN–VV–O–446a, Grade 1120 oil at 155°F±5°, as follows:

   Oil applied to pump pressure port at 150 psi., shall flow through the bleed hole at the rate of 60 qt per hr minimum. Bleed shall shut off between 400–500 psi.

Test Procedure:

1. Connect pump inlet port to suction supply on test bench. Connect the 24-volt dc power source. Connect the pump outlet to a flowmeter calibrated in gpm. with a 1,500 psi. pressure gage teed into the line. Oil to be at 155°F±5°.
2. Stop pump and relieve pressure. Disconnect pump from test setup and connect pressure (outlet) port of pump to pressure source on the test bench. Apply 150 psi. to pressure port. Flow from the bleed hole (from pressure port through pump and out intake port), shall be a minimum of 60 qt per hr. Gradually increase pressure until bleed shuts off. Pressure shall be 400 to 500 psi. Slight leakage after bleed shut off will not be cause for rejection if pump meets requirements of par. 4, following.
3. Start pump and restrict outlet pressure to check relief valve. Relief valve should open at 1,350±50 psi. A momentary surge in pressure up to 2,000 psi. is permissible if pressure immediately drops to 1,350±50 psi.
4. With pump in operation and 1,000 psi. at pressure port flow shall not be less than 3.75 gpm. and current consumption shall not exceed 175 amperes. Duty cycle is one (1) minute "ON" and fifteen (15) minutes "OFF."
5. Relieve pressure. Disconnect pump from test bench. Drain all oil. Cap or plug all ports. Wipe clean. Identify with part number and as having been tested.

Test specifications are often based upon data supplied by the manufacturer of the component but should not become copies of these data. The manufacturer's data should be carefully verified by test and study of the component's construction, and then amplified or altered to suit operating conditions experienced in the application made by the company.

APPENDIX I

TYPICAL INSPECTION JOB EVALUATIONS

In this appendix are shown job evaluations[1] typical of a majority of the inspection department's hourly jobs. Similar data for inspection supervisor positions are not given. These would essentially comprise a reevaluation of one or more of the hourly data, with additional stipulations regarding responsibility and authority. The point evaluations would increase proportionally with the changed requirements and responsibility. Properly prepared job evaluations similar to these can serve as an invaluable tool to simplify personnel control, particularly when used universally throughout the company.

USE OF JOB EVALUATIONS

Before exploring the uses of job evaluations, it is desirable to examine the history and background of this useful tool of modern management. The practice of scientific job analysis and evaluation began to receive industry's recognition in the 1920's, but it was almost cast into limbo by the industrial economies brought about by the early depression years. Its revival was concurrent with the expansion of labor-union activities in the period between 1935 and 1941. During the Second World War it received an additional impetus through the pressure placed upon industry by Selective Service and the War Manpower Commission. It then became necessary for industry to establish an indisputable, scientific basis for manning tables, replacement schedules, deferment requests, and wage increases, in order to cope with the måze of government regulations affecting personnel practices. Following the war, the increased tempo of union activities, with its repeated

[1] Each of these actually comprises a job description or "specification," followed by an evaluation of the relative importance of the job; but for the sake of simplicity they will be referred to herein as *job evaluations*.

waves of demands for increased wages—together with hypersensitive union stewards, eagerly seeking causes for grievances—has served to confirm further the need for sound job evaluations. Today it can be stated without fear of contradiction that job evaluation is an integral part of any progressive personnel policy.

The uses of job evaluations can be classified into four basic groups: (1) specifications for the screening of prospective employees, (2) norms for the transfer of employees to new tasks, (3) controls for merit increases and upgrading, (4) standards for establishing a simplified functional organization through elimination of duplicate and overlapping activities.[2]

One of the most interesting uses of job evaluation is the elimination of inequitable wages for employees accomplishing work of equal value. It is usually found, after analysis of jobs within a company and establishment of evaluations, that certain employees are receiving remuneration far in excess of the actual value of their tasks, while others are underpaid. This is a normal consequence of establishing wages on a hit-or-miss basis, with unplanned merit increases granted according to personal opinions of foremen and supervisors. After all jobs are evaluated, it is possible to remedy the cases of underpaid employees, although it is usually impractical to attempt to correct the instances of overpaid employees. However, once a sound job-evaluation system is established, there should be no reason for repetition of inequitable wage and salary values.

THE POINT SYSTEM OF EVALUATION

It will be observed that the job evaluations shown in this appendix are based upon a *point system.* Seven[3] basic factors governing the requirements, complexity, duties and responsibility of a job are used, with numerical values or *points* assigned to each in

[2] See Bethel, Atwater, *et al.*, "Industrial Organization and Management," Chap. 22, McGraw-Hill Book Company, Inc., New York, 1945, for a detailed discussion of job analysis and evaluation.

[3] This is less than the quantity used by many job-evaluation schemes, as a genuine effort has been made to reduce the typical evaluations contained herein to basic essentials. A separate factor of "education" is omitted. This can be added for highly technical and supervisory job evaluations.

accordance with its magnitude on the particular job. The sum of these points provides the value of the job. The wage range of the job is proportional to its point value, as is shown in the chart below.

This provides for 10 labor grades, each representing a *wage range* within the grade. Any job having a point value inside a particular grade is paid within the wage range established for that

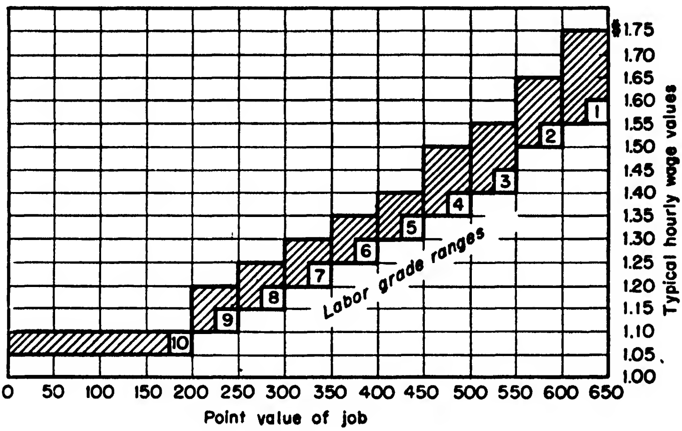


FIG. I:1. Relationship of point values to wages.

grade. The use of wage ranges, instead of point ranges with fixed wage values for each point range, is a vitally important aspect of an effective job-evaluation scheme. *This method makes possible the granting of merit increases as a reward for exceptional performance without necessity of reclassifying or upgrading the employee.* This is particularly true when new employees are started at the bottom wage for their labor grade, making possible two or three 5 cents an hour merit increases within their original grade.

When a system of point ranges and fixed wages within each range is followed, it is impossible to grant merit increases except through upgrading, which often requires the establishment of additional "specialist" classifications. Such practices tend to defeat the purpose of job evaluation, and lead to unnecessary complication of a basically simple procedure.

Considerable literature on the point system of job evaluation is

in existence,[4] and detail discussion of the related procedures and problems would be repetitious. It is sufficient to point out the advantages of this practice and to warn of the pitfall of using fixed wages rather than wage ranges.

TYPICAL INSPECTION JOB EVALUATIONS

In the pages following will be found a selected group of typical inspection job evaluations.[5] These will be of value in conducting job-analysis work in the inspection department.

It is often desirable to establish "A" and "B" classifications for each inspection job, to provide slightly higher evaluations for workmen assigned to especially important or exacting work. In some cases it is also desirable to establish a "C" classification to provide for trainees or inspectors assigned to simple, routine tasks. These lesser job evaluations are substantially repetitions of the "A" classification, but having less exacting duties and responsibilities, and correspondingly lower evaluations. For this reason the "B" and "C" classifications are not given.

INSPECTOR—RECEIVING "A"

(Labor Grade 5)

JOB DESCRIPTION

Summary:

Examination of purchased items.

Work Performed:

Inspecting purchased items to determine conformity to purchase order, drawing prints, specifications, and/or catalogues. Determining physical acceptability through application of visual, precision-instrument, and/or magnetic-particle testing. Verifying conformance to stipulated analysis, process, and strength requirements before accepting an item. Approving acceptable items, and maintaining required records—including receiving report. Issuance of rejection notices when required.

[4] For instance, see Bethel, Atwater, *et al., op. cit.*, pp. 563–569.

[5] Based upon data contained in "Wage Stabilization Plan for Factory Occupations," Consolidated Vultee Aircraft Corp., San Diego 12, Calif., 1943.

Tools and Equipment:

Precision measuring instruments, gages, and test equipment; check fixtures and templates; inspection stamps. All conventional forms of inspection equipment, including surface-finish analyzers.

Knowledge and Ability:

Know receiving inspection methods and procedures, including use of drawing prints, specifications, catalogues, and standards handbooks. Ability to recognize any defect that may exist; and to be acquainted with peculiarities of items purchased from different vendors. Use arithmetic, including decimal and common fractions.

JOB EVALUATION

Factor	*Degree*	*Points*
Mentality:	Interpret drawing prints. Solve mathematical problems of moderate complexity	80
Responsibility:	Loss through error will not exceed $250	40
Mental Application:	Very close mental application	40
Physical Application:	Continuous light physical exertion	20
Job Conditions:	No disagreeable elements	15
Unavoidable Hazards:	Little accident or health hazard	5
Experience:	Minimum 2 years	220
	Total	420

INSPECTOR—FABRICATION "A"

(Labor Grade 4)

JOB DESCRIPTION

Summary:

Inspection of fabricated (except machined), metallic and nonmetallic items; heat-treatment of metals; and chemical or physical processing of metallic and nonmetallic items.

Work Performed:

Inspecting fabricated items for correctness of tooling, dimensions, workmanship, manufacturing methods, heat-treatment, processing, and usability. Approving acceptable items and maintaining necessary records. Issuance of rework and rejection notices when required.

Tools and Equipment:

Precision measuring instruments, gages, test equipment, check fixtures and templates; inspection stamps. All conventional forms of inspection equipment.

Knowledge and Ability:

Know fabrication methods and inspection methods and procedures—including use of drawing prints, specifications, catalogues, and standards handbooks. Ability to use magnetic-particle and hardness testing equipment, templates, heat and time gages; check dimensions to 0.010 in.

JOB EVALUATION

Factor	*Degree*	*Points*
Mentality:	Interpret drawing prints. Solve mathematical problems of moderate complexity	80
Responsibility:	Loss through error will not exceed $250	40
Mental Application:	Very close mental application	40
Physical Application:	Continuous light physical exertion	20
Job Conditions:	No disagreeable elements	15
Unavoidable Hazards:	Little accident or health hazard	5
Experience:	Minimum 3 years	265
	Total	465

INSPECTOR—MACHINED ITEMS "A"

(Labor Grade 3)

JOB DESCRIPTION

Summary:

Inspection of machined items for material, quality, workmanship, dimensions, surface finish, and functional usability.

Work Performed:

Inspecting, with the aid of precision inspection equipment, machined items for conformance with dimensional limits stipulated by drawing prints and specifications. On production machine-shop work the inspector may check the machine setup and first-run item, then approve production followed by sampling inspection. Supervising hardness testing, and determining acceptability of surface finishes. Approving acceptable items and maintaining necessary records. Issuance of rework and rejection notices when required.

Tools and Equipment:

Precision measuring instruments, gages, test equipment; check fixtures and templates; inspection stamps. All conventional forms of inspection equipment—including sine bars, supermicrometers, surface-finish analyzers, and all forms of hardness-testing equipment.

Knowledge and Ability Required:

Know machine-shop methods, and inspection methods and procedures—including use of drawing prints, specifications, catalogues, and standards handbooks. Ability to perform precision layout work involving geometry and trigonometry; check dimensions to 0.0005 in.

JOB EVALUATION

Factor	*Degree*	*Points*
Mentality:	Interpret complex drawing prints. Solve mathematical problems involving geometry and trigonometry	100
Responsibility:	Loss through error will not exceed $500	60
Mental Application:	Very close mental application	40
Physical Application:	Continuous light physical exertion	20
Job Conditions:	No disagreeable elements	15
Unavoidable Hazards:	Little accident or health hazard	5
Experience:	Minimum 4 years	300
	Total	540

INSPECTOR—WELDING "A"

(Labor Grade 4)

JOB DESCRIPTION

Summary:

Inspection of fusion-welded items

Work Performed:

Inspecting fusion-welded items for structural soundness, conformance to drawing prints and usability. Supervising pressure tests to proof soundness of welds. Forwarding welded items requiring magnetic-particle inspection to proper department or group, and verifying presence of magnetic inspection acceptance stamp on all items returned as satisfactory. Verifying that all required processing is properly accomplished. Approving acceptable items and maintaining necessary records. Issuance of rework and rejection notices when required.

Tools and Equipment:

Precision measuring instruments, gages, standard and special test equipment; inspection mirrors; inspection stamps.

Knowledge and Ability:

Thorough knowledge of welding theory and shop methods and of welding inspection methods and procedures. Understand related chemical and physical processing operations. Know all applicable welding specifications. Ability to check dimensions to $1/64$ in. or $1/2$ deg., using drawing-print data; solve problems involving decimal and common fractions.

JOB EVALUATION

Factor	*Degree*	*Points*
Mentality:	Interpret drawing prints. Solve mathematical problems of moderate complexity	80
Responsibility:	Loss through error will not exceed $250	40
Mental Application:	Very close mental application	40
Physical Application:	Continuous light physical exertion	20
Job Conditions:	No disagreeable elements	15
Unavoidable Hazards:	Little accident or health hazard	5
Experience:	Minimum 3 years	265
	Total	465

INSPECTOR—GENERAL ASSEMBLY "A"

(Labor Grade 4)

JOB DESCRIPTION

Summary:

Inspection of subassemblies, assemblies, and related installations.

Work Performed:

Inspecting sub and primary assemblies, together with related installations for completeness, workmanship, conformance to drawing prints, interchangeability, and usability. Checking rivet installations, torque values on bolts, and related operations; verifying and/or accomplishing functional tests. Inspecting mating of assemblies, including approving removal of completed assemblies from jigs. Approving acceptable items and maintaining necessary records. Issuance of rework and rejection notices when required.

Tools and Equipment:

Precision measuring instruments, gages, and standard and special test equipment; check fixtures and templates; inspection mirrors; inspection stamps.

Knowledge and Ability:

Knowledge of company assembly methods and tooling and of assembly inspection methods and procedures. Ability to perform and/or verify required functional tests. Knowledge of required chemical and physical processing operations. Know all related specifications. Check dimensions to 0.010 in., using drawing-print and/or specification data. Solve problems involving decimal and common fractions.

JOB EVALUATION

Factor	*Degree*	*Points*
Mentality:	Interpret drawing prints. Solve mathematical problems of moderate complexity	80
Responsibility:	Loss through error will not exceed $250	40
Mental Application:	Very close mental application	40
Physical Application:	Slight physical exertion	10
Job Conditions:	No disagreeable elements	15
Unavoidable Hazards:	Little accident or health hazard	5
Experience:	Minimum 3 years	265
	Total	455

INSPECTOR—FINAL ASSEMBLY "A"

(Labor Grade 2)

JOB DESCRIPTION

Summary:

Final inspection of completed end items prior to presenting for customer inspection or forwarding to stores or to Shipping.

Work Performed:

Verifying completeness; compliance with drawing prints and specifications; and incorporation of all required changes in completed end items. Making required final operational and performance tests. Determining correctness of painting, assembly, and installation work; adherence to workmanship standards; and completeness of inspection

log, including final check for satisfaction of all assembly "squawks" and shortages. Approving acceptable end items and maintaining necessary records. Issuance of rework and rejection notices as required.

Tools and Equipment:

Precision measuring instruments, gages, standard and special test equipment; check fixtures and templates; inspection mirrors; inspection stamps.

Knowledge and Ability:

Thorough knowledge of final assembly methods, tests, and tooling; and of company and customer inspection methods and procedures. Understand all applicable customer and company specifications. Understand all related chemical and physical processing operations. Ability to perform and/or supervise final functional and performance tests. Check dimensions to 0.010 in. or ½ deg., working from drawing prints or specifications. Solve problems involving geometry and trigonometry.

JOB EVALUATION

Factor	*Degree*	*Points*
Mentality:	Interpret complex drawing prints and specifications. Solve mathematical problems of average complexity	100
Responsibility:	Loss through error may exceed $1,000	100
Mental Application:	Very close mental application	40
Physical Application:	Continuous light physical exertion	20
Job Conditions:	No disagreeable elements	15
Unavoidable Hazards:	Little accident or health hazard	5
Experience:	Minimum 4 years	300
	Total	580

INSPECTOR—SALVAGE "A"

(Labor Grade 1)

JOB DESCRIPTION

Summary:

Inspection, investigation, and disposition of rejected items while serving as a member of the salvage committee.

Work Performed:

Determining, as chief inspector's representative on the salvage committee, the practicability of salvaging rejected items. Final authority on scrapping items unsuited for salvage acceptance. Reinspecting rejected items when considered necessary. Making recommendations for disposition of rejected items as either acceptable "as is," as a deviation, after rework, or suitable only for scrap. Conducting salvage investigations in any area of the factory and at outside producers' plants. Approving items accepted after completion of salvage action and maintaining necessary records. Issuance of rework, rejection, and scrap notices.

Tools and Equipment:

Precision measuring instruments, gages, standard and special test equipment; check fixtures and templates; inspection mirrors; inspection stamps.

Knowledge and Ability:

Thorough knowledge of manufacturing methods and processes; and company quality standards, salvage methods, procedures, and limitations. Understand all applicable company and customer specifications. Check dimensions to 0.0005 in. or 1/10 deg., working from drawing prints or specifications. Solve problems involving geometry and trigonometry.

JOB EVALUATION

Factor	*Degree*	*Points*
Mentality:	Interpret complex drawing prints and specifications. Solve mathematical problems of average complexity	100
Responsibility:	Loss through error may exceed $1,000	100
Mental Application:	Intense mental application	50
Physical Application:	Continuous light physical exertion	20
Job Conditions:	No disagreeable elements	15
Unavoidable Hazards:	Little accident or health hazard	5
Experience:	Minimum 5 years	325
	Total	615

INSPECTOR—SHIPPING "A"

(Labor Grade 4)

Job Description

Summary:

Inspection of all items, including spares and complete end items prior to shipment to customers, including examination of packaging and crating.

Work Performed:

Inspecting all items taken from stores for shipment for completeness, deletions or additions ordered by the customer, previous final inspection acceptance, interchangeability, and conformance to painting or other finish requirements. Approving acceptable items, packaging, crating, packing sheets; and maintaining necessary records. Issuance of rework and rejection notices as required.

Tools and Equipment:

Simple measuring instruments, such as micrometers and scales; standard gages; inspection mirrors; inspection stamps.

Knowledge and Ability:

Thorough knowledge of company quality standards; and shipping methods, procedures and "paper." Interpret complex drawing prints and sales orders. Understand company and customer specifications. Solve mathematical problems involving decimal and common fractions.

Job Evaluation

Factor	*Degree*	*Points*
Mentality:	Interpret drawing prints. Solve mathematical problems of moderate complexity	80
Responsibility:	Loss through error will not exceed $1,000	80
Mental Application:	Very close mental application	40
Physical Application:	Continuous light physical exertion	20
Job Conditions:	No disagreeable elements	15
Unavoidable Hazards:	Little accident or health hazard	5
Experience:	Minimum 2½ years	245
	Total	485

INSPECTOR—OUTSIDE PRODUCTION "A"

(Labor Grade 1)

Job Description

Summary:

Inspection of items purchased from outside producers; usually accomplished at the outside production source.

Work Performed:

Inspecting at outside production plants, including approval of setups, first-piece inspection, and sampling examination of completed lots. Advising outside producer's inspection management of required quality standards, and maintaining liaison between company and outside producer's inspection departments. Approving acceptable items and maintaining necessary records, including follow-up on requests for information. Issuance of rework and rejection notices as required.

Tools and Equipment:

Precision measuring instruments, gages, standard and special test equipment; check fixtures and templates; inspection mirrors, inspection stamps.

Knowledge and Ability:

Detail understanding of manufacturing methods, outside production and procedures, and company quality standards. Understand all applicable specifications and contractual obligations. Ability to interpret correctly magnetic-particle, fluorescent-penetrant, X-ray, and similar indications. Check precision dimensions, working from drawing prints and specifications. Solve mathematical problems involving geometry and trigonometry.

Job Evaluation

Factor	*Degree*	*Points*
Mentality:	Interpret complex drawing prints and specifications. Solve mathematical problems of average complexity	100
Responsibility:	Loss through error may exceed $1,000	100
Mental Application:	Very close mental application	40
Physical Application:	Continuous light physical exertion	20
Job Conditions:	No disagreeable elements	15
Unavoidable Hazards:	Little accident or health hazard	5
Experience:	Minimum 6 years	345
	Total	625

INSPECTOR—TOOLING "A"

(Labor Grade 1)

Job Description

Summary:

Inspection of all types of tooling during manufacture, proofing, production usage, and rework.

Work Performed:

Inspecting all types of precision tools and dies, including outside procured tooling, and precision measuring instruments and test equipment, drill jigs, milling fixtures, master plates, jigs and fixtures, templates, wood and metal patterns, plaster patterns and mock-ups—using tool design and engineering drawing prints, and templates to check for workmanship, completeness, accuracy, and practicability. Approving acceptable tooling and maintaining necessary records. Issuance of rework and rejection notices as required.

Tools and Equipment:

Precision measuring instruments including transits and precision levels; gages; standard and special test equipment; tooling gages and templates; inspection mirrors; inspection stamps.

Knowledge and Ability:

Detail knowledge of tooling manufacturing methods and procedures. Ability to set up and supervise all necessary tooling tryouts and test runs. Usually a tooling inspector specializes in one of the major groups of tooling, but he may be called upon to inspect any type of tooling. Check precision dimensions, working from drawing prints and loft layouts. Solve complex mathematical problems involving geometry and trigonometry.

Job Evaluation

Factor	*Degree*	*Points*
Mentality:	Interpret complex drawing prints and specifications. Solve mathematical problems of average complexity	100
Responsibility:	Loss through error may exceed $1,000	100

Factor	*Degree*	*Points*
Mental Application:	Very close mental application	40
Physical Application:	Occasional difficult or strenuous physical effort	30
Job Conditions:	No disagreeable elements	15
Unavoidable Hazards:	Little accident or health hazard	5
Experience:	Minimum 6 years	345
	Total	635

INSPECTOR—EXPERIMENTAL "A"

(Labor Grade 1)

JOB DESCRIPTION

Summary:

Inspection of experimental manufacturing for all types of items developed by the company.

Work Performed:

Inspecting for proper processing, tooling, mock-up, assembly jigs, the inspection of assemblies in jigs, and tooling. All types of fabrication and assembly operations are involved, including templates and form blocks, welding, and final-assembly testing. Approving acceptable items, and maintaining necessary records. Issuance of rework and rejection notices as required.

Tools and Equipment:

Precision measuring instruments, including transits and precision levels; gages; standard and special test equipment; check fixtures and templates; inspection mirrors; inspection stamps.

Knowledge and Ability:

Maintain liaison with planning, tooling, and engineering departments during development of experimental items. Thorough knowledge of manufacturing methods and procedures, to permit determination of proper methods, in absence of formal planning instructions. Ability to determine usability of items from a functional standpoint, dimensional conformance to drawing print, workmanship; and for proper fabrication, assembly, and tooling through all stages of experimental manufacturing. Ability to establish basic dimensions and practicable dimensional limits, in the absence of complete engineering information.

Check precision dimensions, working from drawing prints and loft layouts. Solve complex mathematical problems involving geometry and trigonometry.

JOB EVALUATION

Factor	*Degree*	*Points*
Mentality:	Interpret complex drawing prints and specifications. Solve mathematical problems of average complexity	100
Responsibility:	Loss through error will not exceed $1,000	80
Mental Application:	Very close mental application	40
Physical Application:	Occasional difficult or strenuous physical effort	30
Job Conditions:	Occasional exposure to disagreeable conditions	25
Unavoidable Hazards:	Exposure to serious accident hazard	35
Experience:	Minimum 5 years	325
	Total	635

ESTABLISHMENT OF DEGREE VALUES

All evaluations for the degree of various factors appearing in these job evaluations are based upon *average* conditions. For instance, the possible loss through error is based upon the damage for which the employee would be wholly responsible and is the average value for a single occurrence—not an extreme maximum.

APPENDIX II

TYPICAL INSPECTION SPECIFICATIONS

It has been pointed out in Chap. 5 that inspection specifications can be grouped into three broad classifications: (1) inspection operation sheets, used for relatively simple precision inspection work; (2) methods bulletins issued to guide complex, lengthy precision inspection; and (3) production inspection specifications detailing precision operations on certain items for the benefit of both inspection and manufacturing departments.

Inspection operation sheets are described and illustrated in Chap. 5, and do not merit additional discussion in the appendix.

INSPECTION-METHODS BULLETIN

These standards are normally issued by the inspection engineering group, and are intended primarily for use by Inspection personnel. An example of an inspection standard of this type is shown in the following methods bulletin used by the aircraft division of Fairchild Engine and Airplane Corporation to control the inspection of forgings, castings, extrusions, and steel heat-treated assemblies.

Inspection-methods Bulletin No. IMB–G–8

Revision IV. This bulletin supersedes and cancels IMB–G–8, Rev. III, and IMB–G–42.

Subject: Inspection of forgings, castings, extrusions, and steel heat-treated assemblies.

I. *Purpose:*

The purpose of this bulletin is to outline a procedure for the inspection and inspection handling of magnesium, aluminum-alloy, and

steel forgings, castings, extrusions, and steel heat-treated assemblies.

II. *References:*

1. QQ-M-151—Metals, General Specification for the Inspection of.
2. AN-A-23—General Specifications for Castings, Aluminum.
3. AN-QQ-H-186a—Heat-treatment of Aluminum Alloys; Process for.
4. AN-M-36—Magnesium-alloy, Sand Casting.
5. AN-I-25—Heat-treatment of Magnesium-alloy Castings.
6. AN-I-26—Radiographic Inspection.
7. MPS-PR-23—Operation and Use of Brinell Hardness Tester.
8. MPS-PR-24—Operation and Use of Rockwell Hardness Tester.
9. MPS-PR-28—Operation and Use of Barcol and York Hardness Testers.
10. SPB 870-38—Magnaflux Inspection.
11. SPB 870-3—Manufacturing Inspection Stamps.
12. FSD 6500—Steel Replacement and Substitution Chart.

III. *Definitions:*

1. Machined castings and forgings shall be considered those castings and forgings upon which machine-shop operations have been performed.
2. Aluminum and magnesium heat-treated castings referred to herein shall be considered those castings which have been solution heat-treated or solution heat-treated and aged.
3. Class A aluminum, steel, and magnesium castings as referred to herein shall be considered those castings having a margin of safety less than 900 per cent as determined by static test.
4. Class B aluminum, steel, and magnesium castings as referred to herein shall be considered those castings having a margin of safety in excess of 900 per cent as determined by static test.
5. X-ray classification is called out on all casting blueprints.

IV. *Flow Charts:* (Attached)

1. Assembly hardness inspection.
2. Castings hardness inspection.
3. Aluminum-forgings and extrusions hardness inspection.
4. Steel-forgings hardness inspection.

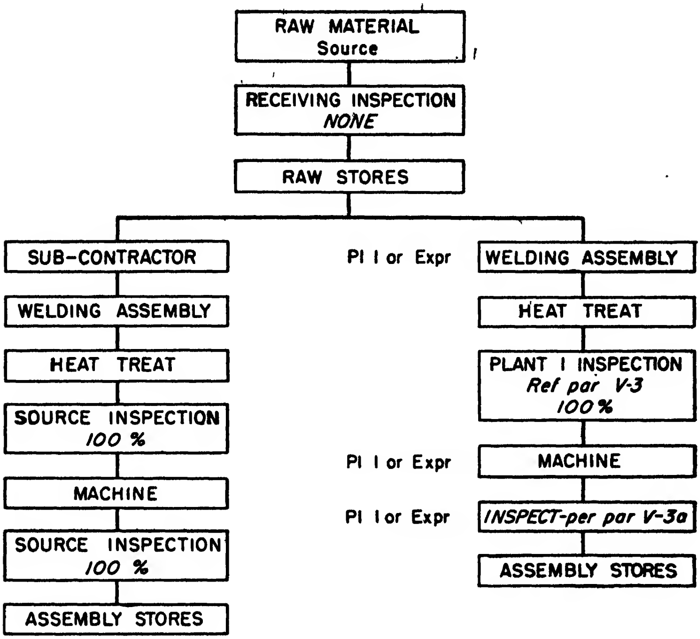


CHART 1. Assembly hardness inspection.

V. *General:*

1. The attached flow charts are to be used to determine the location at which hardness inspections shall be conducted.
2. The inspection of steel castings after machining will be only to determine that a HT stamp has been applied to the part. If not present, the casting will be rechecked and, if acceptable, stamped.
3. All steel welded heat-treated assemblies will be checked 100 per cent after heat-treat and before machining and, if acceptable, will be stamped, except as follows:
   a. Any assembly having parts the size of which are over or near the maximum heat-treat size (ref. 12) and which will have more than 3/16 in. material per surface removed by later machining operations, will be checked 100 per cent after heat-treat, but before machining. They will not be stamped but will have a white identification tag attached, which shall be stamped. Upon completion of all machining operations, the assembly will be reinspected for hardness and, if acceptable, will be stamped.

b. The classification of assemblies per par. V–3a, above, shall be the sole responsibility of the materials and processes inspection foreman, who will post the listing of assemblies to be checked after machining.

4. Assemblies that are checked by coupon only shall be stamped after heat-treat, and will not require hardness inspection after machining.
5. The inspector must be familiar with the operation and use of the following hardness testers:
   a. Rockwell—ref. 8.
   b. Barcol—ref. 9.
   c. Brinell—ref. 7.
6. Inspection of castings and forgings shall comprise:
   a. Radiographic inspection (castings only, in accordance with engineering schedules applicable to the X-ray classification of the castings).
   b. Magnetic inspection on steel forgings when required (ref. 10).

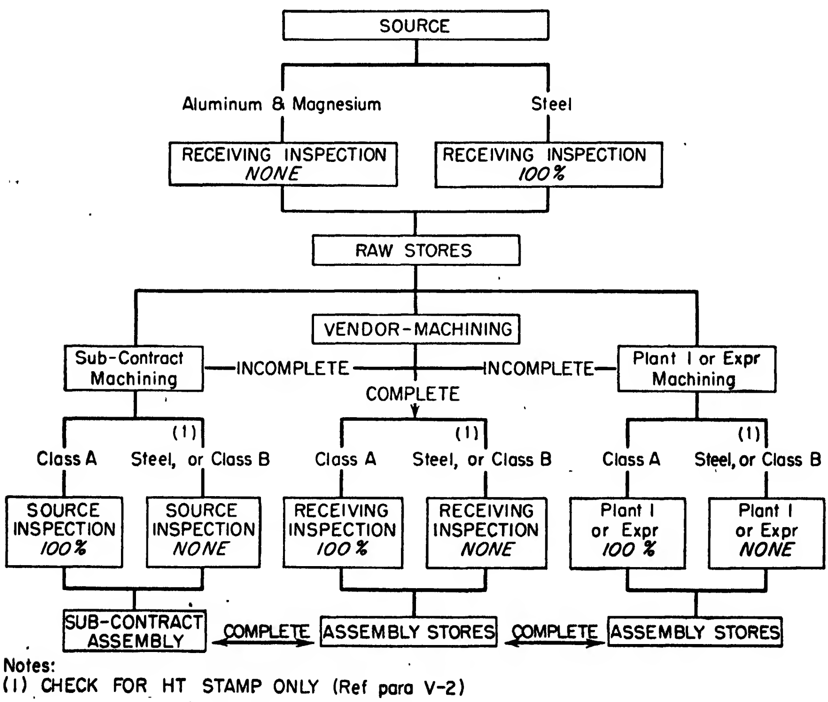


CHART 2. Hardness inspection of castings.

c. Material inspection: 100 per cent.
d. Heat-treat inspection (refer to charts).
e. Dimensional inspection (see par. VI–6).
f. Finish inspection.
(1) *Acceptance* shall be indicated by fixation of the inspector's heat-treat, magnaflux, or detail stamp.
(2) *Rejection or rework* orders shall bear a complete and concise statement by the inspector, regarding the reason or reasons therefore, including the actual measured heat-treat value.

VI. *Inspection Procedure:*

1. *Heat-treat Castings*

a. Class A magnesium, steel, and aluminum heat-treated castings shall be checked as follows:
(1) Hardness test (refer to Chart 2).
(2) Test bars to represent each inspection lot shall be tested to determine conformance with the physical properties specified in the applicable specifications (Ref. 1).

b. Class B magnesium and aluminum heat-treated castings shall be checked by test bars only.

c. Class B steel heat-treated castings shall be checked 100 per cent for conformance to specified blueprint conditions.

2. *Heat-treat Inspection of Forgings*

Each part required by specification or blueprint to be in a heat-treat temper shall be tested with a hardness tester (see Ref. 7, 8, and 9). Coupons processed with the parts will be tested with an approved hardness tester, and if the tensile strength is within the limits specified, the parts shall be considered satisfactory. The inspector shall identify each part; if acceptable, by fixation of his heat-treat stamp adjacent to part number. Parts will be checked in accordance with Charts 3 and 4.

3. *Radiographic Inspection of Castings*

Radiographic inspection of castings shall be performed on Class A, A1, and A2 castings at time of receipt from vendor, to insure freedom from cracks, blowholes, porosity, etc., in excess of permissible limits as defined by laboratory standards. The incidence of such radiographic inspection shall be in accordance with engineering schedules applicable to the X-ray

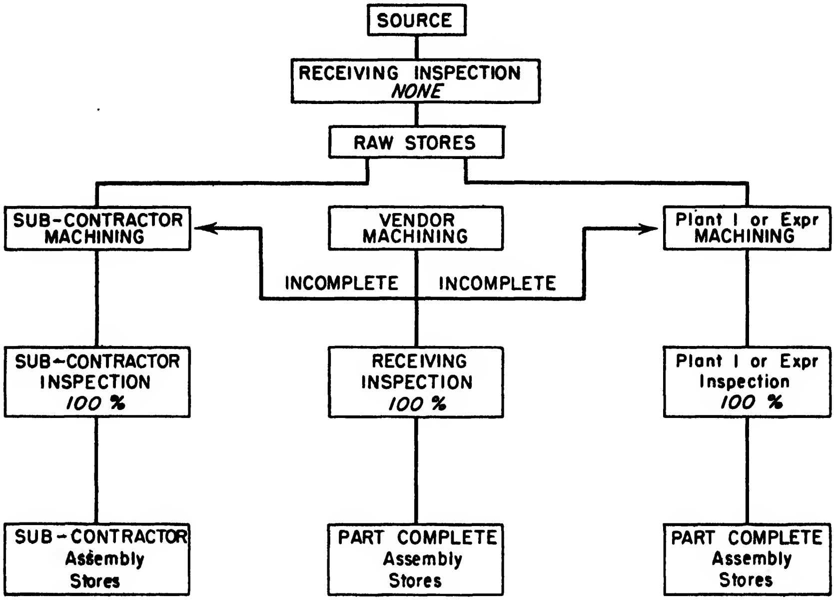


CHART 3. Hardness inspection of aluminum forgings and extrusions.

classification of the castings. X-ray stamps shall be affixed adjacent to the part number on those castings adjudged acceptable.

4. *Magnetic Inspection of Steel Forgings and Castings*
   a. Magnetic inspection of steel forgings shall be performed (to assure freedom from cracks, laps, and structural defects in excess of permissible limits) upon receipt from vendor, and also after machining in accordance with ref. 10.
   b. Magnetic inspection of steel castings *may* be performed (to assure freedom from cracks) upon receipt from vendor, and also after machining.
      (1) Defective class A castings shall have the area of defect marked and shall be forwarded to X-ray laboratory.
      (2) The X-ray laboratory will accept or reject class A castings solely on the basis of their radiographic findings, aided by magnaflux indications.
      (3) No magnetic inspection stamps shall be applied to castings.
5. *Material Inspection*

   Material inspection shall comprise a visual examination to

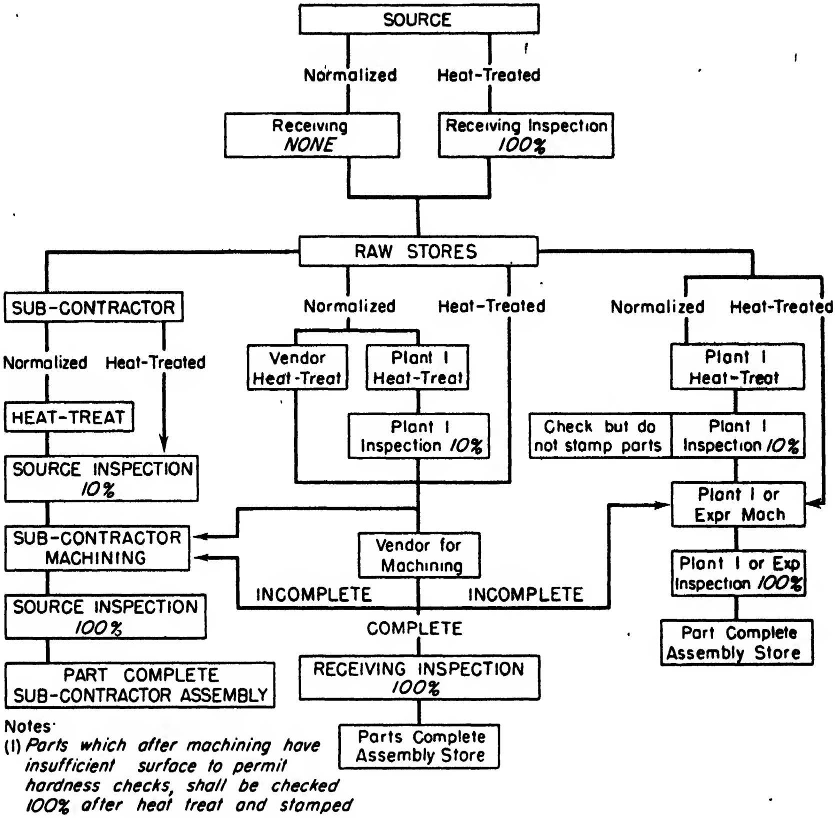


CHART 4. Hardness inspection of steel forgings.

insure that parts meet the requirements of the blueprint and work order and that they are free from obvious defects. Reference shall be made to test reports relative to chemical composition.

6. *Dimensional Inspection*

a. Dimensional inspection shall be performed after all machining and heat-treat operations have been completed.

b. Dimensional inspection (Receiving Inspection only).

(1) One (1) piece of each lot or shipment received by Receiving Inspection shall be processed through layout inspection to ascertain that:

(*a*) Dimensions are in correct relationship from and/ or to vertical and horizontal lines or planes, as prescribed by drawing requirements.

(*b*) Location of holes, offsets, sides, etc., are in relationship to each other and to vertical and/or horizontal lines or planes as prescribed by drawing requirements.

(*c*) Interchangeability as established will be maintained at source by resident inspector, as assigned.

(2) The entire lot or shipment shall be dimensionally inspected, to ascertain the correctness of radii, diameters, depths, thickness, threads, etc.

7. *Finish Check*

Each part shall be subjected to a visual, comparative check against established finish standards, to determine the acceptability of the finish.

PRODUCTION INSPECTION SPECIFICATION

Production inspection specifications, which are prepared by the inspection engineering group in close collaboration with the engineering and manufacturing departments, detail the inspection, assembly, and test operations performed on a complex unit. The manufacturing departments assemble and install the unit in accordance with the production inspection specifications, and Inspection checks the manufacturing operations in accordance with the same document. Thus close coordination between manufacturing and inspection work is assured, as both groups are guided by identical information.

Inspection specifications may be quite extensive in the case of certain complex mechanisms, such as the following example extracted from an inspection specification used by the aircraft division of Fairchild Engine and Airplane Corporation.

Manufacturing Process Specification [1] No. FA–37

Model C–XX Landing Gear Assembly—Inspection, Installation, and Operation of.

[1] In this discussion "production inspection specification" has been selected as a generic term to identify all types of detail specifications issued by Inspection for the guidance of both inspection and manufacturing departments, although some companies may assign different titles to the same class of document.

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Section I—Receiving Inspection

1. When the *Delco actuators* are received in Plant 26 they will be checked for the following items:
   1. Check for transit damage.
   2. Check visually for
      a. General damage.
      b. Rubber dust cover for cuts, tears, or other damage.
      c. Proper seating where dust covers attach.
      d. No paint on dust covers or inside of "cannon" plug.
      e. Proper lock wiring.
      f. Black band to indicate hardened stop pin. Painted on release shaft housing.
   3. Check for presence of all stamps:
      a. Heat-treat.
      b. Magnaflux.
      c. Weld.
      d. Delco.
      e. FAD.
      f. USAF.
   4. On main gear actuators, using tools provided (see Fig. II:1), the travel of the release shaft may be accurately checked in the following manner:

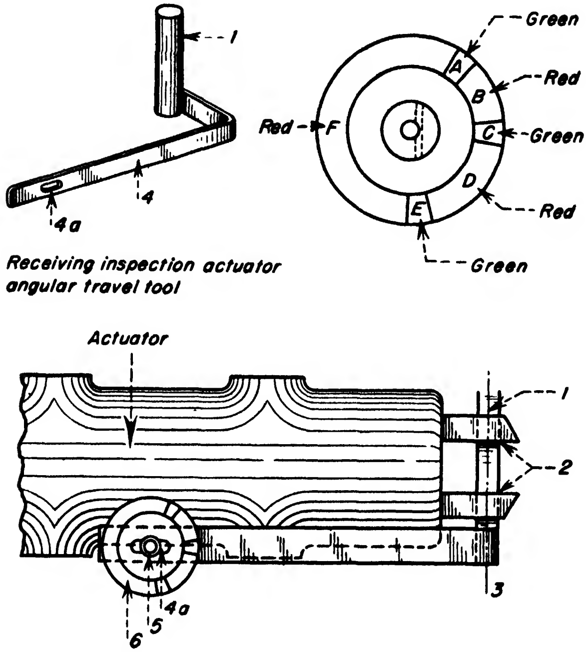

FIG. II:1. Identification and usage of special tools for checking main gear actuator release shaft travel.

a. Place stud 1 in holes at 2.
b. Rotate about axis at 3 until hole 4*a* in tool 4 falls over release shaft at 5.
c. Place graduated disk 6 over release shaft and insert bolt through hub and slot in shaft to position disk.
d. Allowable disengagement tolerance will be read in area *C*. If pointer on 4 falls outside of area *C*, actuator is incorrect, and should be rejected.
e. Rotate disk clockwise to stop in actuator. This shows limit of travel in disconnect position.
f. Rotate disk counterclockwise to stop in actuator. This shows limit of travel in connected position. If pointer of 4 falls in areas *B*, *D*, *F*, travel is incorrect, and actuators should be rejected.

5. On nose gear actuators, using a similar tool provided, the travel of the release shaft may be accurately checked in the above manner.

6. Check for excessive (more than ⅛ in.) deflection of jack shaft. If excessive play is found, notify Inspection Engineering. Check is to be made by estimation without removing dust cover *unless* excessive play is present. If so, remove dust cover and check with tools provided. (MLG–CG–11, NLG–CG–12).
7. To prevent electrical operation of gears before preoperational inspection, tamper-seal the "cannon" plug on the actuators with masking tape and seal the masking tape with a decal stamped by Inspection.
   Note: (*Care must be taken at all times to prevent carrying or striking the dust cover against the screw jack, as it has sharp edges and will cut or damage the dust cover.*) If repair is needed, proceed as follows:
   Repair of Actuator Dust Cover (Procedure in accordance with Standard Repair 2–3.)
   a. Roughen the patch surface and the area of the bellows adjacent to the tear with a coarse file to facilitate bonding.
   Note: Rubber particles and other foreign matter *must not* enter through the tear onto the actuator screw.
   b. Clean the roughened areas thoroughly with a cloth moistened with naphtha, thinner, or carbon tetrachloride.
   c. Apply one thin, even coat of EC–669 cement to each surface to be bonded, and allow it to dry until tacky.
   Note: When cement does not rise to form a pyramid when finger-tested, it will be considered tacky. Cleaning solution or cement *must* not enter the tear in the bellows.
   d. Form patch (rejected bellows) from an area conforming to area being repaired and with sufficient overlap beyond the tear to insure a tight bond.
   e. Apply firm pressure to the bonded area, to insure a satisfactory bond.
   f. Do not flex the repaired bellows for 12 hr. (minimum).
   g. Apply talc or soapstone over bare cement in area of repair, after drying, to prevent adherence to adjacent surfaces.

B. When the *emergency extension shock absorbers* are received at Plant 26, they will be inspected for the following items:

1. Visual damage.
2. Proper orifice size with hole gages.
   Nose gear snubber—0.0625 in.
   Main gear snubber—0.0625 in.

3. Proper seal. Three (3) "O" ring installations (see Figs. II:2 and II:3).

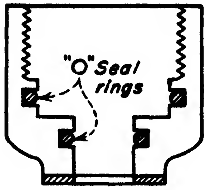

FIG. II:2. End-cap O-ring installation.

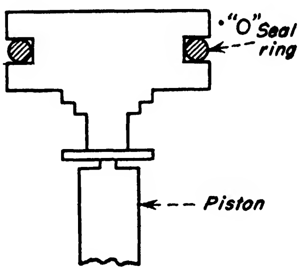

FIG. II:3. Piston O-ring installation

4. Proper length and location of flutes (see Fig. II:4).
5. Main-gear snubber:
   a. With the plunger fully compressed to the bottom within the cylinder, a maximum dimension of 24.62 in. must be held.
   b. With the plunger fully extended to bottom within cylinder, a minimum dimension of 45.09 in. must be held.
6. Nose-gear snubber:
   a. With the plunger fully compressed to bottom within cylinder, a maximum dimension of 14.78 in. must be held.
   b. With the plunger fully extended to bottom within cylinder, a minimum dimension of 25.00 in. must be held.

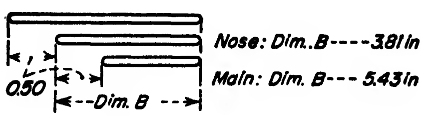

FIG. II:4. Flute dimensions.

C. When the nose-gear shock absorber strut is received, it will be inspected for

1. Alignment in fully extended position. To accomplish this, put the strut in test jig 78–420000CJ–1.
2. Angular travel of swivel mechanism. Travel of 62 deg from 0 deg in both directions.
3. Safeties of nuts, bolts, and any damage that might have occurred during transit.

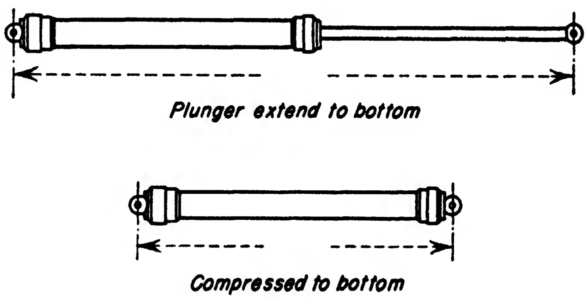

FIG. II:4A. Snubber extended and compressed positions.

Subsequent sections of this production inspection specification describe and illustrate the landing-gear electrical system, subassembly and installation procedures, preoperational and operational inspection and testing. These are not given herein, as the purpose of quoting a portion of this typical specification is to illustrate the nature of this type of standard, rather than to provide complete information on a particular specialized item.

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